PB-244 312

CHARACTERIZATION AND UTILIZATION OF MUNICIPAL AND UTILITY SLUDGES AND ASHES

VOLUME III. UTILITY COAL ASH

DAYTON UNIVERSITY

PREPARED FOR
NATIONAL ENVIRONMENTAL RESEARCH CENTER

MAY 1975

DISTRIBUTED BY:
NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

237054

EPA-670/2-75-033c
May 1975

PB244312

Environmental Protection Technology Series

CHARACTERIZATION AND UTILIZATION OF MUNICIPAL AND UTILITY SLUDGES AND ASHES
Volume III. Utility Coal Ash

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

National Environmental Research Center
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-670/2-75-033c	2.
3. PB 244 312	
4. TITLE AND SUBTITLE: Characterization and Utilization of Municipal and Utility Sludges and Ashes Volume III - Utility Coal Ash	5. REPORT DATE: May 1975; Issuing Date
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S): Hecht, N. L. and Duvall, D. S.	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS: University of Dayton Research Institute, 300 College Park Drive, Dayton, Ohio 45469	10. PROGRAM ELEMENT NO. 1DB064; ROAP 24ALH; Task 008
	11. ~~CONTRACT~~/GRANT NO. R800432
12. SPONSORING AGENCY NAME AND ADDRESS: National Environmental Research Center, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268	13. TYPE OF REPORT AND PERIOD COVERED: Final Report
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
Project Officer: Richard Carnes 513/684-4487
See also: Volumes I, II, and IV, EPA-670/2-75-033a, b, and d.

16. ABSTRACT

The residue from the burning of coal, collected from the stack effluent and the bottom of the boiler unit, is another solid waste disposal product that the community must be concerned with. Since 1940 more than 300 million tons of this coal ash has been generated, of which only about 30% has been utilized. In this study the nature of coal ash has been defined, the quantities produced have been determined and the locations of the major utilities generating the coal ash have been established. In addition, the anticipated compositional changes and quantities to be generated in the future resulting from expanded energy requirements, advancements in technology and pollution controls have been evaluated. This study also included a review of current disposal and utilization practices.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Residues, *Coal, Disposal, Utilization, *Composition	Generation rates, Technology advances, Energy requirements, Pollution controls	13B

PRICES SUBJECT TO CHANGE

18. DISTRIBUTION STATEMENT: Release to public	19. SECURITY CLASS (This Report): Unclassified	21. NO. OF PAGES: 74
	20. SECURITY CLASS (This page): Unclassified	22. PRICE: $4.25-2.25

EPA Form 2220-1 (9-73)

U.S. GOVERNMENT PRINTING OFFICE 1975-657-592/5372 Region No. 5-11

EPA-670/2-75-033c
May 1975

CHARACTERIZATION AND UTILIZATION OF MUNICIPAL AND UTILITY SLUDGES AND ASHES

Volume III

Utility Coal Ash

by

N. L. Hecht and D. S. Duvall
University of Dayton Research Institute
Dayton, Ohio 45469

Program Element No. 1DB064
Research Grant No. R800432

Project Officers

R. A. Carnes and D. F. Bender
Solid and Hazardous Waste Research Laboratory
National Environmental Research Center
Cincinnati, Ohio 45268

NATIONAL ENVIRONMENTAL RESEARCH CENTER
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

ia

REVIEW NOTICE

The National Environmental Research Center--Cincinnati has reviewed this report and approved its publication. Approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

This study was involved with the ash formed from burning coal in utility boilers. Characterization, disposal, and possible utilization of the ash were discussed. Changes in technology and possible effects on coal ash of the future were considered.

A. W. Breidenbach, Ph.D.
Director
National Environmental
Research Center, Cincinnati

ABSTRACT

The residue from the burning of coal, collected from the stack effluent and the bottom of the boiler unit, is another solid waste disposal product that the community must be concerned with. Since 1940 more than 300 million tons of this coal ash has been generated, of which only about 30% has been utilized. In this study the nature of coal ash has been defined, the quantities produced have been determined and the locations of the major utilities generating the coal ash have been established. In addition the anticipated compositional changes and quantities to be generated in the future resulting from expanded energy requirements, advancements in technology and pollution controls have been evaluated. This study also included a review of current disposal and utilization practices.

TABLE OF CONTENTS

		PAGE
SUMMARY		1
CONCLUSIONS AND RECOMMENDATIONS		5
COAL ASH CHARACTERIZATION		6
COAL ASH UTILIZATION		34
REFERENCES		46
APPENDIX I	REGIONAL FUEL USE BY SELECTED ELECTRIC UTILITIES	53
APPENDIX II	ANALYSES AND FUSIBILITY OF ASH FROM VARIOUS U.S. COALS	58
APPENDIX III	ASH UTILIZATION	64

ACKNOWLEDGEMENT

The authors wish to acknowledge the assistance and support rendered during this study by Professor S. J. Ryckman, G. S. Skivington, and R. A. Ralston.

The authors also wish to acknowledge the assistance provided by the two project officers: R. A. Carnes and D. F. Bender.

SUMMARY

The burning of coal produces an ash residue which is derived from the inorganic mineral constituents in the coal and the organic material not completely burned. In coal burning utility boilers, the coal ash residue is collected from the bottom of the boiler unit (bottom ash) and from the air pollution equipment through which the stack gases pass (fly ash). Over 46 million tons of coal ash were collected in 1972 by some 500 power plants in the United States. The distribution of power plants defines the ash producing regions of the country. The largest concentration of power plants is in the middle Atlantic and the east north central states. There are very few coal burning power plants west of the Mississippi River.

The coal ash residues recovered from the boiler units are primarily iron aluminum silicates with additional amounts of lime, magnesia, sulfur trioxide, sodium oxide, potassium oxide, and carbon. About 12 percent of the coal burned is recovered as coal ash residue. A high percent of that ash is in the glass state (50-90 percent), with small quantities of quartz, mullite, magnetite, and hematite mineral phases. An average chemical analysis for coal ash would be;

SiO_2	45%
Al_2O_3	25%
Fe_2O_3	14%
CaO	4%
MgO	2%
TiO_2	1%
K_2O	2%
Na_2O	1%
SO_3	2%
C	4%
B, P, Mn, Mo, Zn, Cu, Hg, U, Th	Trace

The specific chemical composition of a coal ash is primarily dictated by the geology of the coal deposit and the operating parameters of the boiler unit.

About 70 percent of the coal ash residue is collected as fly ash. For any specific boiler unit the fly ash and bottom ash will have essentially the same chemical composition except that the bottom ash will be lower in carbon content. Fly ash generally occurs as fine spherical particulates having an average particle diameter of 7μ. The fly ash will range in color from light tan to black, depending on the carbon content, and have an average specific gravity of 2.3. The pH of the fly ash will vary from 6.5 to 11.5 and will average about 11. About 20 volume percent of the fly ash will be composed of very lightweight particles which float on the surface of the ash lagoon. These lightweight particles have a true density of about 0.5 g/cc and are termed cenospheres. These cenospheres are carbon dioxide and nitrogen filled microspheres of silicate glass ranging in size from 20μ to 200μ.

The bottom ash is collected either as an ash or a slag depending on the particular boiler design. The ash material is grey to black in color, quite angular and has a porous surface. The slag particles are normally black angular particles having a glass appearance. The bottom ash particles will have an average particle diameter size of 2-1/2 millimeters and an average specific gravity of 2.5.

Advancing boiler design technology and the establishment of stricter air pollution codes for boiler facilities may alter the nature of the coal ash produced in future years. The various proposed desulfurization processes, coal fractionation processes, and new designs for electric generating facilities can result in coal ash and slag products considerably different from those currently being produced.

The coal fractionation processes used for obtaining clean gas or liquid fuels and the reconstitution of the coal to obtain a clean low-ash, low-sulfur fuel results in the production of slag and char residues at the conversion facility rather than at the power plant. The liquefaction process produces a filter cake of inorganic materials. The fluidized-bed gasification generates a powder waste composed of the fluid media, the coal residue, and a calcium sulfate precipitate. In the high temperature gasification process the residue is a glassy slag. The chemical composition and physical characteristics of these residues have not been well defined due to the relative newness of these processes.

Conversion of existing boiler units to fluidized bed units will result in a change in the nature of the coal ash recovered. Ash from this process will be less vitrified, due to the lower operating temperatures. Also, the quantity of crystalline material increase (quartz, magnetite, alumina, and calcium sulfate) and the alkaline content is likely to be higher.

Several processes have been developed for meeting the newly established codes for control of SO_2 emissions from stationary sources. A number of these processes completely alter the nature of the collected fly ash and others add a new residue material to the solid waste stream. Most of these processes require the wet or dry injection of an alkaline powder (limestone, dolomites, etc.) to absorb the gaseous sulfur in the stack effluent. The wet injection or scrubbing process (limestone) which appears to be more prevalent, in most cases, results in the generation of a new waste ($CaSO_4$) rather than modifying the fly ash. Preliminary calculations indicate that these wastes will most likely result in a doubling of utility residue waste. Since these desulfurization processes are still largely in the development or pilot state, it is not possible to adequately define the chemical characteristics at this time.

Since 1966, coal ash utilization has fluctuated around 15 to 16 percent of the total ash collected in the United States. From data supplied by the Edison Electric Institute it is apparent that the single largest application for coal ash is as mineral fill material for roads and other construction products. Average European usage of bituminous coal ash for 1972 was almost 27 percent and in Belgium, France, Poland, the United Kingdom, and West Germany, usage exceded 50 percent. The two largest applications for European coal ash were filler on construction sites and for concrete block.

Although a multitude of technically sound applications have been developed for the utilization of coal ash, usage has been very limited. Yearly fluctuations in the quantities of coal ash used in the various applications developed, would suggest that firm markets have not been established for these coal ash uses. At the present time, appreciable quantities of coal ash are only being used as fill material for roads and other construction projects. The use of coal ash as a replacement for cement in concrete and concrete products is starting to increase and a more stable market is being established. The use of fly ash in concrete offers a number of technical advantages, e.g., improved mechanical strength and improved resistance to sulfate leaching, etc. Fly ash, and boiler slag are also being used to an appreciable extent for road base stabilization and as filler in asphalt. Boiler slag is particularly noted for increasing the skid resistance of asphalt pavement. The use of coal ash as a raw material in the

manufacture of Portland cement is another application where usage has increased during the past several years. Recent research results indicate that large quantities of coal ash can also be effectively used for agriculture, land, and water reclamation projects. Fly ash has been effectively used in reclaiming surface mine spoil (high pH of ash neutralizes mineral soil), as a soil nutrient, and as an aid in the treatment of polluted waters.

A number of the applications developed for coal ash have the potential to utilize the entire quantity of ash generated. These include agriculture and land recovery, road base stabilization, structural fill, and cement and concrete products.

Effective utilization of coal ash in the many defined applications requires that the potential user be favorably impressed with the product and the product be economically advantageous. The economic competitiveness of coal ash is impaired by the discriminatory federal practices that favor virgin materials in freight rates and depletion allowances. Improved federal economic policy toward secondary materials like coal ash would enhance their utilization potential.

CONCLUSIONS AND RECOMMENDATIONS

In 1972, approximately 46 million tons of coal ash were collected from the burning of some 350 million tons of coal in over 500 utilities. About 16% of the ash collected was utilized. Therefore, over 38 million tons of ash had to be removed to disposal sites at the expense of the utility. At the present time, disposal costs are approaching $2.00/ton of ash disposed. By 1980, coal consumption by the utilities, to meet expanding energy needs, is predicted to be almost 500 million tons. The projected increase in coal consumption coupled with the decreasing quality of available coal (higher ash content) will result in substantially increased quantities of coal ash. Stricter air pollution codes (reduction of particle and sulfur emission) will also result in an increase in the quantity of coal ash collected.

The technology for a diversity of applications, for coal ash, has been well established. The potential market for most of these applications is quite good and several of these applications have potential markets which can utilize all the ash collected. The major need at this time is the initiation of programs which will encourage greater use of the coal ash in these applications. With the anticipated increase in coal ash collected and the increase in disposal costs, the need for programs to stimulate ash utilization becomes more important. Some study should be devoted toward determining the types of programs best suited for effectively stimulating increased ash utilization. Studies characterizing ash residue from fluidized bed boiler units, gasification and liquefaction processes, and desulfurization processes are needed if effective utilization technology for these wastes are to become available. Further, implementation of these new processes will result in the generation of new waste products that can significantly add to the disposal problem unless applications for these materials are available.

COAL ASH CHARACTERIZATION

The burning of coal produces an ash residue derived from the inorganic mineral constituents and the organic material not completely combusted. The quantity of organic residue is primarily a function of the combustion conditions. The nature of the inorganic residue is, primarily, a result of the geologic and geographic factors associated with the coal deposits.

The quantity and character of the coal ash generated will to a large extent be dictated by the boiler unit in which the coal is burned. The ash collected from the stack effluent is termed fly ash and the ash collected from the bottom of the boiler is termed slag or bottom ash depending on its condition of collection. Boiler units can be classified into three main categories:

1. stoker fired units,
2. cyclone furnace units,
3. pulverized coal fired units.

Boilers fired by underfeed and traveling grate stokers emit the smallest amount of fly ash (10 to 20% of the total ash content). The fly ash generated in these units is relatively coarse and only about 5% is less than 10 microns. The spreader stoker units, which burn more of the coal in suspension, generate a greater quantity of fly ash. The amount of fly ash produced will depend, to a large extent, on the amount of smaller than 1/8 inch coal fired in the unit. Between 15 to 55% of the total ash collected in a spreader stoker unit will be fly ash and 10 - 45% of this material will measure less than 10 microns.

In a cyclone unit from 80 to 85% of the coal ash never reaches the combustion gas because burning takes place at such high rates that the melting point for the ash is exceeded causing most of the ash to melt and be continuously tapped from the bottom of the furnace as a slag. The ash that does enter the gas stream is very fine and about 90% is less than 10 microns. The cyclone units operate on minimum excess air and fly ash in the gas stream can be as high as 2-1/2 lbs. per 1,000 lbs. of gas.

In the pulverized coal (PC) fired units the coal is burned in suspension and the majority of the coal ash enters the gas stream during combustion. About 65% of the fly ash will be minus 10 microns. There are two types of PC units; wet bottom and dry bottom. In the wet bottom units, up to 50% of the ash can be prevented from entering the gas stream while for dry bottom units only 20 to 25% of the ash is retained in the

furnace. Fly ash loading in the dry bottom units can run as high as 12 lbs. per 1,000 lbs. of gas. The PC units are quite widely used in industry, especially when boiler capacities in excess of 50,000 lbs. of steam per hour are required. (1)

Coal ash constitutes between 8 to 14% of the coal burned and averages about 12%. As the coal consumption in the United States continues to increase to meet the increasing demands for electrical energy, there will be a corresponding increase in ash production. In addition the quality of the coal being used is deteriorating and the ash content is increasing, (1, 2, 3, 4, 5) Some of the sub bituminous and lignite coals now being used contain 15 to 18% noncombustible mineral constituents.

In 1970 about 517 million tons of bituminous coal were consumed in the United States. Of this amount 320.5 million tons, 61.9%, were used by the electric utilities; 101.4 million tons, 19.7%, were used in other manufacturing processes;and 12.4 million tons, 2.4%, were used in retail markets. Of the total bituminous coal used in 1970 about 80% was used in applications resulting in the production of coal ash. In addition some 6 million tons of lignite coal were used by utilities and some of the oil used by eastern utilities also produced fly ash. In 1970 about 39.2 million tons of coal ash were produced by the nation's utilities. In 1972 over 46 million tons of ash were generated by some 500 power plants throughout the United States. By 1978 an additional 86 coal burning facilities are expected to be in operation resulting in added generation of coal ash. (2, 6)

Utilization of coal ash has lagged significantly behind production and has created a serious solid waste management problem. Since World War II over 300 million tons of ash have been generated, of which only about 3% has been utilized. In 1972 only about 16.5% of the total ash produced was utilized, which means that over 38 million tons of ash had to be removed to disposal sites at the expense of the utility. Ash disposal costs range from $0.50 per ton to $3.00 per ton and average more than $1.00 per ton. (2, 3, 6, 7, 8)

The projection for coal consumption and ash production till 1980 is shown in Figure 1. It should be noted that the data presented are for the use of bituminous coal, since very little lignite coal is currently being used in the United States. The projected coal consumption by 1980 for the utilities is estimated to be about 500 million tons and the expected ash production will exceed 50 million tons. These projections definitely indicate the need for a greater effort toward establishing more effective programs for coal ash utilization. (2)

This geographical distribution of ash production is also an important factor for consideration. It is obvious that the distribution of power

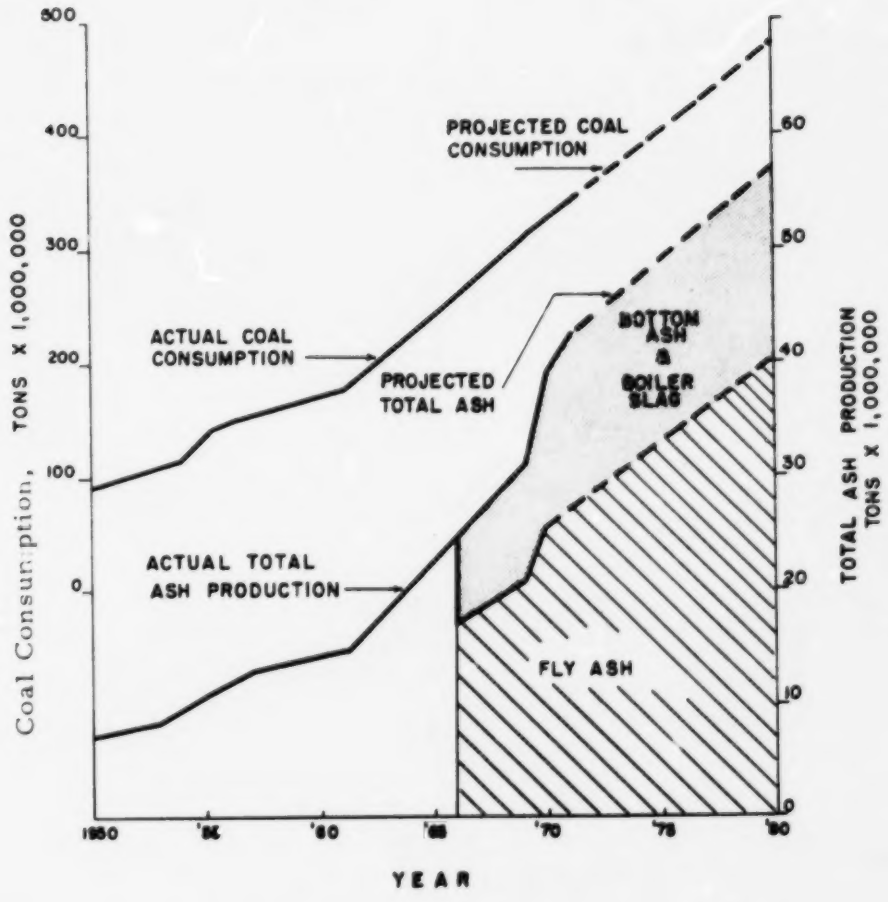

Figure 1. Coal Consumption and Total Ash Production, by U.S. Utilities, Millions of Tons. (2)

plants will define the ash producing regions of the country. The geographical distribution of the major power stations in the United States is shown in Figure 2 and a compilation of coal consumption by geographical areas for 1971 is presented in Table I. A more detailed compilation of electric utilities around the country and their coal requirements for 1970, with projections for 1975 to 1980, is presented in Appendix I. From these compilations it is apparent that the major concentration of ash production is located in the large metropolitan areas presently served by electric utilities using coal to generate power. The Middle Atlantic area, which includes New York, New Jersey, and Pennsylvania, and the East North Central area, which includes Illinois, Indiana, Michigan, Ohio, and Wisconsin consume the largest amounts of coal in the generation of electrical energy. These are followed in order by the South Atlantic, East South Central, West North Central, New England, and the mountain area. (6, 9)

Although the large utilities in the Middle Atlantic, East North Central, and East South Central areas are in rather close proximity and, therefore, afford coal ash availability, large areas still exist where coal ash is unavailable. Very little fly ash is available west of the Mississippi River, in the New England area, and in parts of the South. Of the approximately 500 power plants in the United States that burn coal, only about 200 consume over 400,000 tons of coal per year. However, these 200 power plants generate approximately 90% of the total quantity of ash produced. (6, 9)

The chemical and physical characteristics of the coal ash will, to a large extent, dictate the applications for which the ash can be used. Although coal ash is a complex heterogeneous material, highly dependent on the type of coal and combustion process used, it possesses common chemical and physical characteristics. Coal ash is, primarily, an iron-aluminum-silicate with additions of lime, magnesia, sulfur trioxide, sodium and potassium oxides, and carbon. Traces of heavy metals are also found in the coal ash. A high percent of the ash is in the glassy state. For any one type of coal the chemical composition of the different ash fractions, fly ash, bottom ash, and slag will be similar except that the bottom ash and slag will have a lower carbon content. A schematic showing the concentration range for the major constituents in the United States fly ash is shown in Figure 3. A more detailed compilation of the chamical constituents in coal ash is presented in Table II. The solubility of coal ash in distilled water is presented in Table III. (1, 2, 3, 8, 10, 11, 12, 13)

As stated, the resultant coal ash composition will be dictated by the minerals incorporated in the particular coal deposit. A listing of the common minerals found in the United States coals is presented in Table IV and a compilation of ash analysis for various United States coals is presented in Appendix II.

Figure 2. Power Stations. (6)

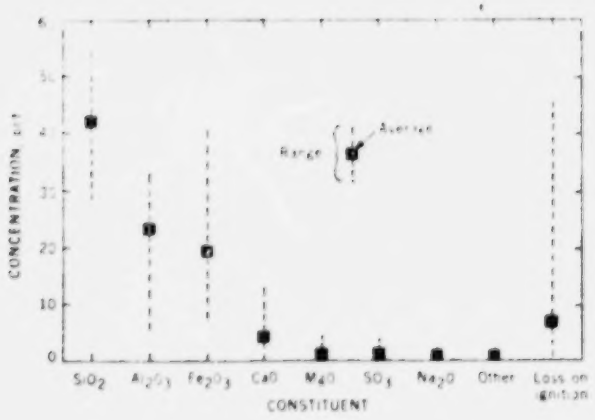

Figure 3. Range and Average of Analyses of United States Fly Ashes. (8)

TABLE I

COAL BURNED BY U.S. UTILITIES, 1971, GEOGRAPHICAL DISTRIBUTION [9]

Geographical Area	Coal Burned (Thousand Tons/Year)	Percent
New England	2,701	0.8
Middle Atlantic	43,869	13.4
East North Central	119,444	36.5
West North Central	27,898	8.5
South Atlantic	65,903	20.1
East South Central	51,565	15.7
West South Central	10	Negligible
Moutain	15,885	4.9
Pacific	None	0
TOTAL	327,358	----

[1] Geographic areas are as follows:
New England: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut.
Middle Atlantic: New York, New Jersey, Pennsylvania
East North Central: Ohio, Indiana, Illinois, Michigan, Wisconsin
West North Central: Minnesota, Iowa, Missouri, Kansas, Nebraska, South Dakota, North Dakota.
South Atlantic: Maryland, Delaware, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida.
East South Central: Mississippi, Alabama, Tennessee, Kentucky.
West South Central: Louisiana, Arkansas, Texas, Oklahoma.
Moutain: New Mexico, Arizona, Nevada, Colorado, Utah, Wyoming, Montana, Idaho.
Pacific: California, Oregon, Washington.

NOTE: Western States rely heavily on hydroelectric power.

TABLE II

CHEMICAL CONSTITUENTS OF COAL ASH

Constituents	Range (%)	Average (%)
Silica (SiO_2)	20 - 60	48
Alumina (Al_2O_3)	10 - 35	26
Ferric Oxide (Fe_2O_3)	5 - 35	15
Calcium Oxide (CaO)	1 - 20	5
Magnesium Oxide (MgO)	0.25 - 4	2
Titanium Dioxide (TiO_2)	0.5 - 2.5	1
Potassium Oxide* (K_2O)	1.0 - 4.0	2
Sodium Oxide* (Na_2O)	0.4 - 1.5	1
Sulfur Trioxide (SO_3)	0.1 - 12	2
Carbon (C)	0.1 - 20	4
Boron (B)	0.01 - 0.6	trace
Phosphorus (P)	0.01 - 0.3	trace
Manganese (Mn)	0.01 - 0.3	trace
Molybdenum (Mo)	0.01 - 0.1	trace
Zinc (Zn)	0.01 - 0.2	trace
Copper (Cu)	0.01 - 0.1	trace
Mercury (Hg)	0.0 - 0.02	trace
Uranium (U) and Thorium (Th)	0.0 - 0.1	trace

* Alkalies

TABLE III

COAL ASH SOLUBILITY IN DISTILLED WATER [14]

Soluble Ions	Range (for 1-1.7% dry solids)
Ca^{++}	200-850 ppm
Mg^{++}	185-400 ppm
$SO_4^{=}$	200-250 ppm
K^{+}	Trace
Na^{+}	Trace
$PO_4^{=}$	0-5 ppm
BO_3^{-}	0-10 ppm

TABLE IV

COMMON MINERALS IN U. S. COALS [8]

Pyrite, marcasite - FeS_2

Chalcopyrite - $CuFeS_2$

Arsenopyrite - $(FeS_2 \cdot FeAs_2)$

Stibnite - Sb_2S_3

Gypsum - $CaSO_4 \cdot 2H_2O$

Calcite - $CaCO_3$

Quartz - SiO_2

Siderite - $FeCO_3$

Kaolinite - $Al_2Si_2O_5(OH)_4$ [7]

Dolomite - $CaMg(CO_3)_2$

Apatite - $Ca_5(F, Cl, OH)(PO_4)_3$

Mica - $KAl_2(Si, Al)_3O_{10}(OH)_2$

During combustion, the inorganic minerals in the coal are subjected to furnace temperatures between 2500°F and 3100°F. At these temperatures the minerals will react to form various silicates, oxides, sulfates, and glassy phases which make up the coal ash. The predominate crystal phases observed are mullite, quartz, hematite, and calcium sulfate. The distribution range for these mineral phases is compiled in Table V. (3,15)

Fly ash generally occurs as fine spherical particulates ranging in diameter from 0.5μ to 100μ, and having an average diameter of 7μ. A profile of a typical fly ash particle size analysis is shown in Figure 4. The carbon phase is present in the fly ash as irregularly shaped lace-like particles 10μ to 300μ across. A general sieve analysis for fly ash is presented in Table VI. Photomicrographs of fly ash samples are shown in Figures 5a and b. (8,11,14,15,16,18,19)

The color of fly ash will range from light tan to gray to black depending on the iron and carbon content. As the carbon content increases, the fly ash will go from gray to black, while increased iron content tends to produce a tan color. The pH of the fly ash will vary from 6.5 to 11.5 and will average about 11. The alkaline nature of the ash enhances its use for neutralization of acidic soil and water. A summary of the typical physical properties of fly ash is presented in Table VII. (11)

The residue from the burning of coal recovered from the bottom of a boiler unit occurs as either bottom ash or slag. In 1972, bottom ash and slag accounted for 32% of the coal ash generated. The condition of this residue will depend on the type of boiler: dry bottom or wet bottom. The dry bottom boilers, which are more common among the newer installations, burn pulverized coal and have open grates at their base. Below the grate is an ash hopper which is generally filled with water. The ash obtained from these types of units is generally gray to black in color, quite angular, and has a porous surface texture. In the wet bottom or slag tap boilers, which burn both pulverized and crushed coal, the residual ash is tapped from the bottom of the boiler unit, in the molten state, into the water-filled ash hopper. The quenched slag is composed primarily of black angular particles having a glassy appearance; in addition some of the particles are rod shaped. The larger slag particles have a somewhat porous texture and the very fine particles are very glassy. A grain size distribution curve for various bottom ash and slag samples is shown in Figure 6 and a comparison of the grain size distribution curves for bottom ash and fly ash from a PC unit is shown in Figure 7. A typical slag sieve analysis is given in Table VIII. An average value for the specific gravity of bottom ash and slag is 2.5. In general, boiler slags tend to have greater specific gravities than dry bottom ash. However, it should be noted

TABLE V

MINERAL PHASES FOUND IN COAL ASH[15]

Phase	Percent
Quartz	0-4
Mullite	0-16
Magnetite	0-30
Hematite	1-8
Glass	50-90

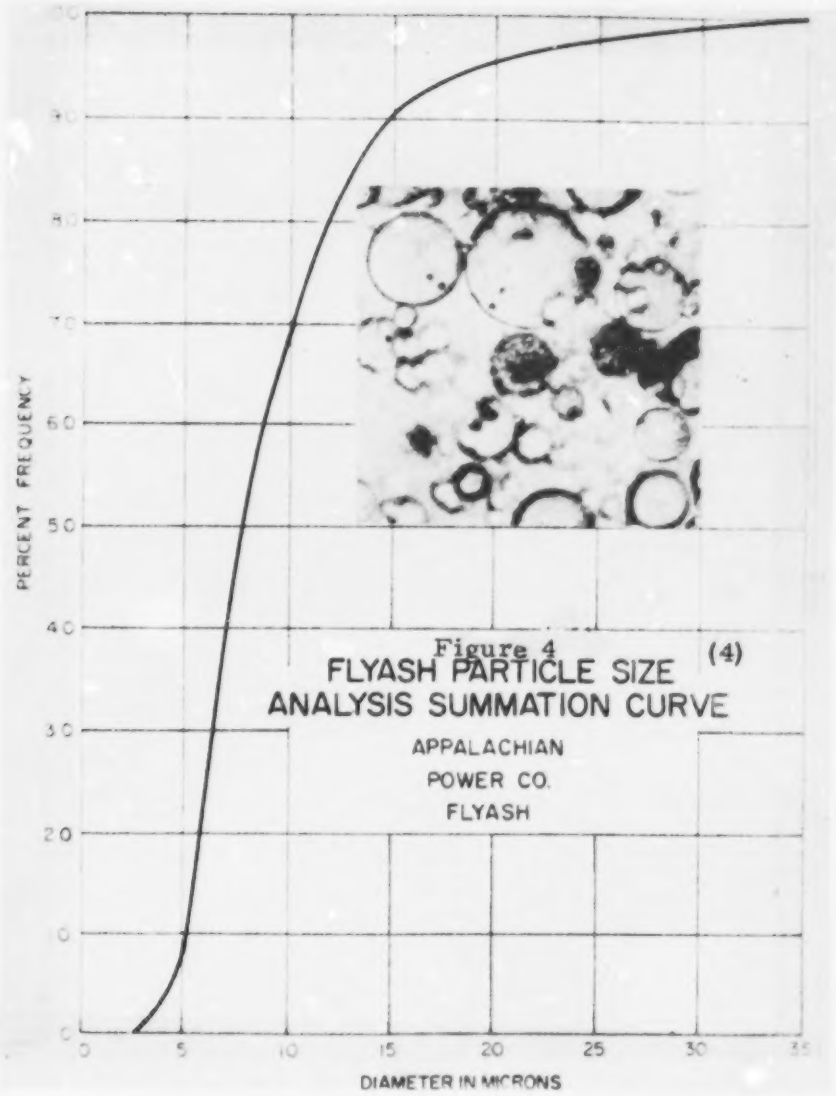

Figure 4 (4)

FLYASH PARTICLE SIZE ANALYSIS SUMMATION CURVE

APPALACHIAN POWER CO. FLYASH

TABLE VI

TYPICAL FLY ASH SIEVE ANALYSIS[17]

MESH	PERCENT
<60	1-2
60 to 100	2-5
100 to 150	2-4
150 to 200	4-8
>200	81-91

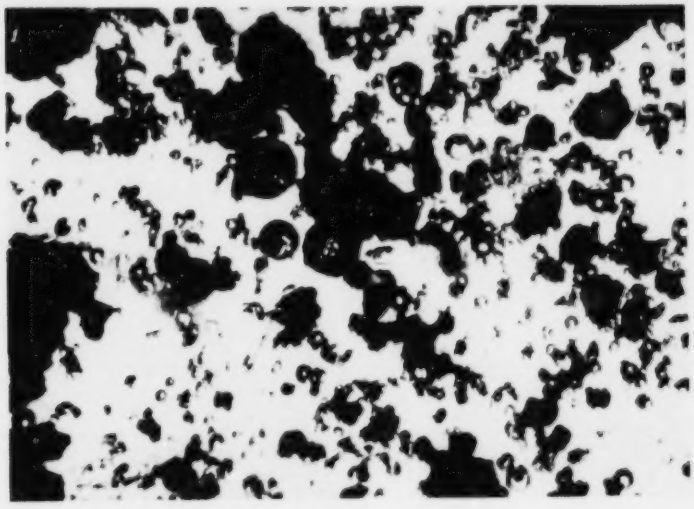

Figure 5a. Photomicrograph of a Fly Ash Showing Angular as well as Rounded Black Particles, Spheroidal Glass and Minute Silica Grains. (15)

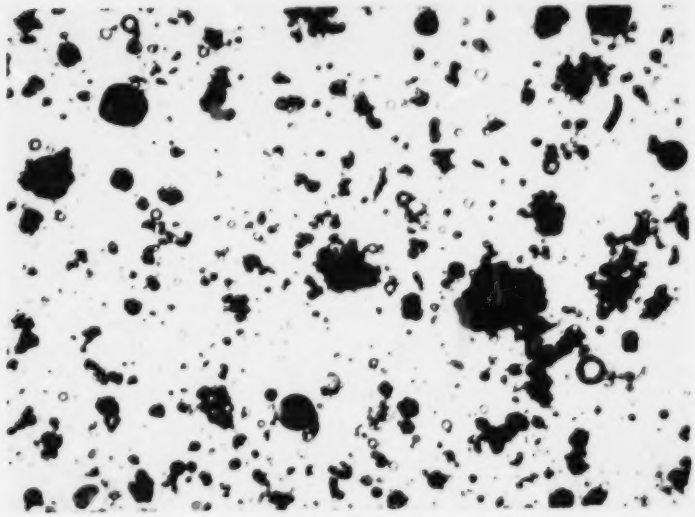

Figure 5b. Photomicrograph of Fly Ash Fraction passing 44-μ Sieve Showing a Large Proportion of Spheroidal Glass and some Rounded Black Particles. (15)

TABLE VII

TYPICAL PHYSICAL PROPERTIES OF FLY ASH
FROM PULVERIZED COAL FIRED PLANTS (3)

Constituent		Range
Range of particle size	microns	0.5-100
Average percent passing No. 325 sieve (44μ)	percent	60-90
Bulk density (compacted)	lb/cu feet	70-80
Specific gravity		2.1-2.6
Specific area/gram	cm^2/g	3,300-6,400

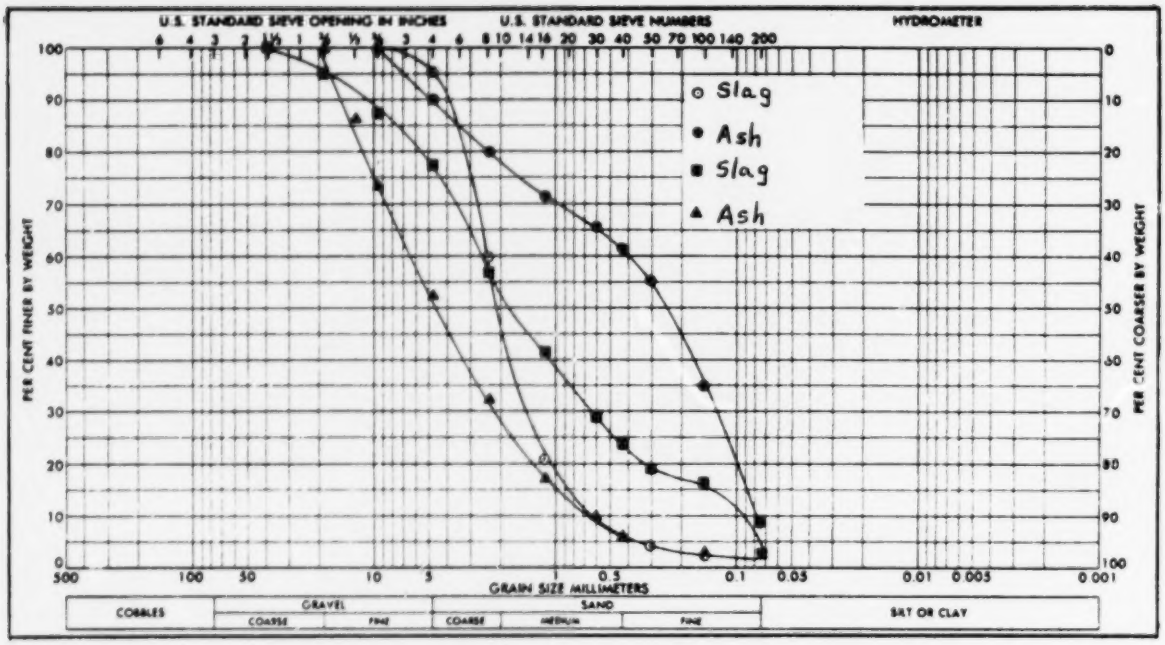

Figure 6. Grain Size Distribution Curves for Selected Samples of Bottom Ash and Boiler Slag. (20)

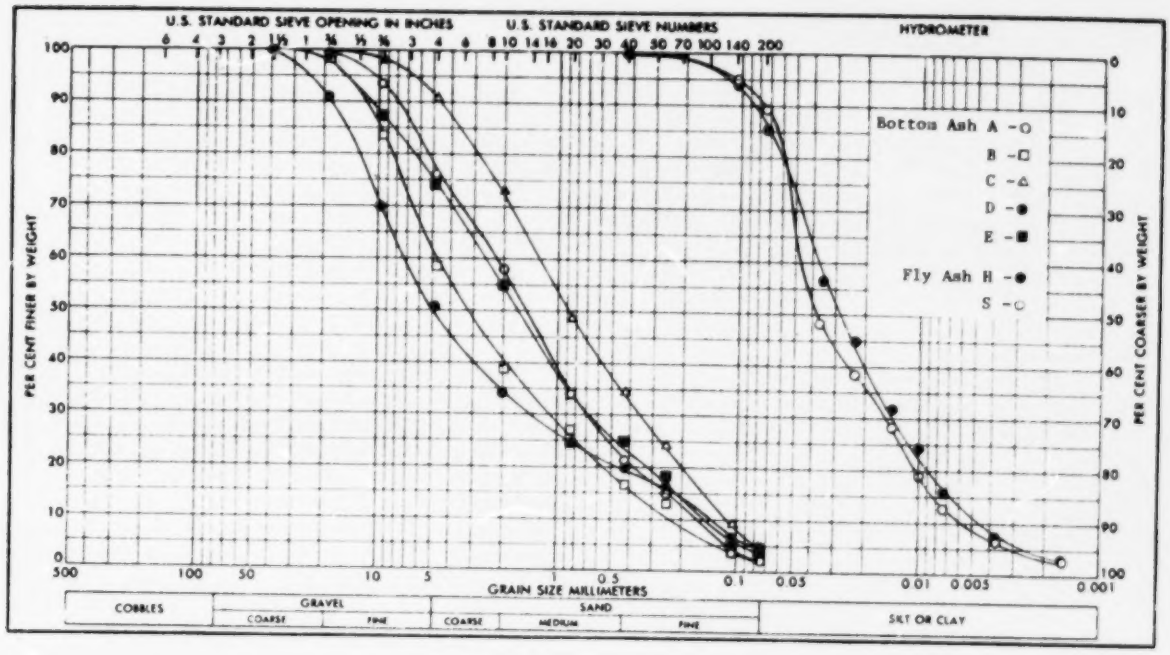

Figure 7. Grain Size Distribution Curves for Bottom Ash and Fly Ash From the Fort Martin Power Station. (20)

TABLE VIII

TYPICAL SLAG SIEVE ANALYSIS [4]

MESH	PERCENT
<10	12-60
10 to 16	10-30
16 to 20	8-26
20 to 48	8-25
48 to 100	1-5
>100	1-5

that the chemical composition for any specific ash will dictate its specific gravity and the iron content will have a major effect. A compilation of specific gravities for several bottom ash and slag samples is presented in Table IX. (15, 20)

Another fraction of coal ash of specific interest is comprised of the very lightweight particles which float on the surface of the ash lagoon. These lightweight particles, termed cenospheres, are carbon dioxide and nitrogen-filled microspheres of silicate glass ranging in size from 20μ to 200μ. The coherent nonporous shell is about 10% of the sphere radius and the true particle density of the sphere ranges between 0.4 g/cc and 0.6 g/cc. The bulk density ranges between 0.25 g/cc and 0.40 g/cc. The collected cenospheres tend to be free of soluble matter and have the following chemical composition;

SiO_2 - 55 to 61%

Al_2O_3 - 26 to 30%

Fe_2O_3 - 4 to 10%

CaO - 0.2 to 0.6%

MgO - 1.0 to 2.0%

Na_2O & K_2O - 0.5 to 4.0%

C - 0.01 to 2.0%

The cenospheres can be as much as 5 weight percent or 20 volume percent of the fly ash generated. Because of its unique characteristics the cenosphere fraction appears to have a considerable utilization potential. (3, 11, 21)

The establishment of new and stricter air pollution regulations for utilities may alter the types of coal ash produced in the next several years. The various proposed desulfurization processes, coal fractionation processes, and new designs for electric generating facilities may result in coal ash and slag products that are considerably different from those currently being produced. Many of the concepts currently under investigation for the fractionation of coal to obtain clean gas or liquid fuels, or the reconstitution of the coal to obtain clean low ash coal will result in the production of slag or char residues at the conversion facility rather than at the power plant. In addition most of the proposed desulfurization processes and new concepts for power generation facilities will result in a modified coal ash at the power plant. Greater utilization of the lignite coal deposits would also result in a modified coal ash composition.

TABLE IX

SPECIFIC GRAVITIES FOR SELECTED BOTTOM ASHES AND SLAGS [20]

Sample No.	Specific Gravity
Bottom ash #1	2.35
Bottom ash #2	2.48
Bottom ash #3	2.28
Bottom ash #4	2.78
Bottom slag #1	2.72
Bottom slag #2	2.47
Bottom slag #3	2.61

Several processes have been developed for meeting the newly established codes for control of SO_2 emissions from stationary sources. Some of these processes completely alter the nature of the collected fly ash and others add an additional solid waste product to the steam generating process. A compilation of the various SO_2 emission control systems and their effect on the fly ash characteristics has been prepared by TVA and is presented in Table X.

One expected type of modified fly ash is that resulting from the injection of limestone or dolomite into boilers to fix gaseous sulfur oxides as solid calcium and magnesium sulfates. Both dry and wet collection processes are being developed. In the dry collection method, gaseous sulfur oxides are absorbed on pulverized limestone or dolomite, which is injected into the furnace above the flame envelope, and collected with fly ash in the precipitators. In the wet collection process, similar injection methods are used but the precipitators are replaced by wet scrubber units, or by a water-limestone/dolomite wash mixture used with the scrubber unit. The widespread use of these processes will result in significant increase in the expected quantities of coal ash. The use of limestone or dolomite injection processes can increase the ash generated by a power plant by a minimum of 50%. At the present time wet limestone or dolomite scrubbing appears to be one of the leading processes for SO_2 removal from stack gases. In the more recent designs electrostatic precipitators are used before the scrubbing stage in order to reduce erosion of the scrubber unit, and result in the generation of two separate waste products: fly ash and calcium sulfate. For purposes of comparison, the ash compositions generated by the combustion of bituminous coal and lignite coal are compared with the ashes obtained in the limestone and dolomite injection processes, in Table XI. The impact of the limestone and dolomite processes are difficult to assess since these processes are currently being utilized primarily in pilot studies and conclusive information is not yet available. However, with technological improvements and the lower cost of this technique, versus other proposed sulfur control processes, it is quite possible that large quantities of modified ash may be produced in the future. It is important to note that the chemistry of this modified ash is considerably different from bituminous ash and it may not be appropriate for many of the same applications. Disposal of this modified ash may also create new problems because of the increased arsenic and mercury content reported in the sulfate sludge, due to the scrubbing action. (3, 22, 23, 24)

TABLE X

CHANGES IN FLY ASH COMPOSITION RESULTING FROM OPERATION OF SO_2 EMISSION CONTROL SYSTEMS (22)

PROCESS	REACTANT	FLY ASH REMOVAL MECHANISM	FLY ASH CHARACTERISTICS
I. Fly ash Characteristics Unchanged			
A. Catalytic Oxidation			
1. Kiyoura	Vanadium, pentoxide catalyst, ammonia	Dry hot electrostatic precipitators(ESP)	Dry fly ash - characteristics unchanged
2. Monsanto	Vanadium, pentoxide catalyst	Dry hot electrostatic precipitators (ESP)	Dry fly ash - characteristics unchanged
B. Dry SO_2 Absorption			
1. Atomics International	Molten carbonate	Dry ESP (hot or standard)	Dry fly ash - characteristics unchanged
2. Hitachi	Activated carbon	Dry ESP (hot or standard)	Dry fly ash - characteristics unchanged
3. Reinluft	Activated charcoal	Dry ESP (hot or standard)	Dry fly ash - characteristics unchanged
4. Alkalized Alumina U.S. Bureau of Mines	Alkalized alumina	Dry ESP (hot or standard)	Dry fly ash - characteristics unchanged
5. Esso-Babcock & Wilcox	Proprietary	Dry ESP (hot or standard)	Dry fly ash - characteristics unchanged
6. Lignite Ash	Lignite ash, calcium hydroxide	Dry ESP (hot or standard)	Dry fly ash - characteristics unchanged
7. DAP-Mn (Mitsubishi)	Manganese dioxide	Dry ESP (hot or standard)	Dry fly ash - characteristics unchanged
C. Wet SO_2 Absorption			
1. Sulfacid (Lurgi)	Sulfuric acid	Dry ESP (hot or standard)	Dry fly ash - characteristics unchanged

Table prepared by Tennessee Valley Authority

TABLE X (continued)

CHANGES IN FLY ASH COMPOSITION RESULTING FROM OPERATION OF SO_2 EMISSION CONTROL SYSTEMS (22)

PROCESS	REACTANT	FLYASH REMOVAL MECHANISM	FLY ASH CHARACTERISTICS
II. Minor Changes to Fly ash Characteristics			
A. Dry SO_2 Absorption			
1. Grillo	Manganese dioxide, manganese hydroxide	Fly ash collects in reactant bed and is separated by decantation during regeneration of the reactant	Dry fly ash plus small quantities reactant and products
B. Wet SO_2 Absorption			
1. Showa Denka	Ammonia	Alternatives:	
		1. Dry mechanical, ESP, or combination of mechanical plus ESP preceding scrubber	Dry fly ash - characteristics unchanged
		2. Wet scrubber	Wet fly ash only (possibly small quantities of reactants and products also present)
2. Potassium Formate (Consolidation Coal Co.)	Potassium formate	Alternatives:	
		1. Dry mechanical, ESP, or combination of mechanical plus ESP preceding scrubber	Dry fly ash - characteristics unchanged
		2. Wet scrubber	Wet fly ash only (possibly small quantities of reactants and products also present)
3. Ionics Inc., Stone & Webster Inc. (Alkaline Scrubbing)	Sodium hydroxide	Alternatives:	
		1. Dry mechanical, ESP, or combination of mechanical plus ESP proceding scrubber	Dry fly ash - characteristics unchanged

TABLE X (continued)

CHANGES IN FLY ASH COMPOSITION RESULTING FROM OPERATION OF SO_2 EMISSION CONTROL SYSTEMS (22)

PROCESS	REACTANTS	FLY ASH REMOVAL MECHANISM	FLY ASH CHARACTERISTICS
		2. Wet Scrubber	Wet fly ash only (possibly small quantities of reactants and products also present)
4. Sodium or Potassium Sulfite Scrubbing (Wellman-Lord)	Sodium sulfite or potassium sulfite	Alternatives:	
		1. Dry mechanical, ESP, or combination of mechanical plus ESP preceding scrubber	Dry fly ash - characteristics unchanged
		2. Wet scrubber	Wet fly ash only (possibly small quantities of reactants and products also present)
III. Fly ash Contains Significant Reactants or Solid Diluents			
A. Dry SO_2 Absorption			
1. Dry Limestone Injection	Calcium carbonate or magnesium carbonate	Dry mechanical, ESP, or combination of mechanical plus ESP	Dry fly ash plus reactants (unreacted and deadburned limestone) and products[3]
2. Foster-Wheeler (Chemical Dihydrate Injection)	Calcium hydroxide	Dry mechanical, ESP, or combination of mechanical plus ESP	Dry fly ash plus reactants (unreacted and deadburned limestone) and products[3]
B. Wet SO_2 Absorption			
1. Chemico-Basic	Magnesium oxide	Wet scrubber	Wet fly ash reactants and products

TABLE X (continued)

CHANGES IN FLY ASH COMPOSITION RESULTING FROM OPERATION OF SO_2 EMISSION CONTROL SYSTEMS (22)

PROCESS	REACTANT	FLY ASH REMOVAL MECHANISM	FLY ASH CHARACTERISTICS
2. Lime/Limestone Wet Scrubber			
a. Limestone injection into furnace			
(1) Limestone (or dolomite) scrubbing Combustion Engineering)	Calcium carbonate or magnesium carbonate	Wet Scrubber	Wet fly ash plus reactants (unreacted and deadburned limestone or dolomite and products[2, 4].
b. Limestone (or dolomite) to scrubber circuit			
(1) Limestone (or dolomite) scrubbing (TVA)	Calcium carbonate or magnesium carbonate	Alternatives: 1. Dry mechanical, ESP, or combination of mechanical plus ESP preceding scrubber 2. Wet Scrubber	Dry fly ash - characteristics unchanged (possibly small quantities of reactants present as a result of boiler injections to control boiler corrosion or improve ESP efficiency) Alternatives: 1. If first stage scrubber is used for fly ash scrubbing only and is discharged to a segregated pond: Wet fly ash only[1, 5].

TABLE X (concluded)

CHANGES IN FLY ASH COMPOSITION RESULTING FROM OPERATION OF SO_2 EMISSION CONTROL SYSTEMS (22)

PROCESS	REACTANT	FLY ASH MECHANISM	FLY ASH CHARACTERISTICS
			2. If first stage scrubber or pond is used for combined fly ash and SO_2 removal: Wet fly ash plus reactants[4] and unreacted limestone[4, 5]

NOTE:

1. Wet scrubbing often subjects the fly ash to very acidic scrubbing liquors which could leach out some of its alkaline components (e.g. Ca, Mg, Na, K).

2. Limestone wet scrubber reactants can possibly include: CaO, $Ca(OH)_2$, $CaSO_3$, $CaSO_4$, MgO, $Mg(OH)_2$, $MgSO_3$, $MgSO_4$ plus small quantities of other compounds and impurities.

3. Dry limestone injection reactants can possibly include: Same as for NOTE 2 except for less sulfites. Also, if the ash is removed dry (e.g., not sluiced to a settling pond), $Ca(OH)_2$ and $Mg(OH)_2$ will not be present.

4. Fly ash and solid diluents will exist in about equal quantities; exact ratio dependent on sulfur and ash content of coal, stoichiometric addition of limestone, etc.

5. Possibly small quantities of reactants and products also present as a result of additives to control pH and to promote the dissolution or otherwise increase the effectiveness of the reactant.

TABLE XI

COMPARISON OF ASH COMPOSITIONS*[24]

Constituent	Bituminous Ash	Lime Modified Ash	Dolomite Modified Ash	Lignite Ash
SiO_2	49. 10	30. 85	30. 81	32. 60
Al_2O_3	16. 25	13. 70	12. 54	10. 70
Fe_2O_3	22. 31	11. 59	10. 72	10. 0
TiO_2	1. 09	0. 68	0. 42	0. 56
CaO	4. 48	33. 58	17. 90	18. 00
MgO	1. 00	1. 49	14. 77	7. 31
Na_2O	0. 05	1. 12	0. 72	0. 87
K_2O	1. 42	0. 71	0. 99	0. 68
SO_3	0. 73	2. 20	8. 09	2. 60
C	2. 21	1. 12	1. 76	0. 11
H_2O soluble	2. 51	22. 11	-----	8. 55

*Percent of Composition

Another new type of ash which may be produced is that resulting from the fluidized-bed, combustion process. Ash from this process will be far less vitrified due to the lower operating temperatures, which range between 1400°F and 2100°F. Although the chemical constituents of the ash from the fluidized-bed process will be similar to the ash from pulverized coal burning units, the quantity of unvitrified (crystalline) material will be greatly increased (Fe_2O_3, quartz, and $CaSO_4$) and the alkaline content may be higher. (3)

A number of pilot studies for the gasification or liquification of coal are currently underway and it is anticipated that several of these processes will be ready for full scale implementation by 1976 - 1977. The conversion of coal to either gas or oil will result in the generation of a residue consisting of some carbon (1-2%), the inorganic minerals trapped in the coal, and precipitated sulfates. The liquification process produces a filter cake residue of inorganic minerals and the fluidized bed gasification process generates a powder waste resulting from the overflow of the bed. This powder waste will contain the fluid media, the coal residue, and in some cases precipitated calcium sulfate when limestone is added to the bed media. In the higher temperature gasification processes the residue will be a glassy slag. The chemical compositions for these various residues have not yet been established. However, as these processes approach implementation the residues will have to be completely characterized and applications for these materials developed. (25, 26)

COAL ASH UTILIZATION

Utilization of coal ash has been quite limited to date, however, there has been a trend toward increased usage in the past few years. A comparison of ash production versus ash utilization from 1966 to 1972 is compiled in Table XII. A detailed breakdown of the uses for coal ash in 1972 is compiled in Table XIII. A breakdown of coal ash utilization from 1969 to 1971 is presented in Appendix III. From Table XIII it can be seen that the major use for coal ash is as mineral fill material for roads and other construction projects. It is also quite apparent that significant quantities of coal ash are removed by private individuals from the power plant at no cost to the utility. It is surmised that much of the coal ash removed is used in the various applications listed under the miscellaneous category of Table XIII. A partial listing for the known uses of ash removed at no cost to the utility was compiled by Edison Electric Institute and is presented in Table XIV. (2, 27)

For comparative purposes a compilation of European ash utilization for 1971 is presented in Table XV and Table XVI. Average European usage of bituminous coal ash for 1972 was 26. 7% and average usage of lignite coal ash for 1972 was 4. 6%. In a number of European countries (Belgium, France, Poland, Finland, United Kingdom, and West Germany) use of bituminous coal ash is very high (50% or higher). Except for France, effective utilization of lignite ash is not wide spread in the European countries even though considerable quantities of lignite ash are produced (36, 353, 000 tons in 1971). (28, 35)

Yearly fluctuations in the quantities of coal ash used (see Appendix III) in the various applications would suggest that meaningful trends have not been well established; thus valid projections for future consumption are difficult to make at this time. However, appreciable quantities of coal ash are being used on a consistent basis as a fill material for roads, construction sites, land reclamation, etc. In addition increased quantities of coal ash are being used as a partial replacement for cement in concrete and concrete products. Fly ash and boiler slag are also being used to an appreciable extent for road base stabilization and as filler in asphalt. Boiler slag is particularly noted for increasing the skid resistance of asphalt pavement. The use of coal ash, as a raw material, in the manufacture of portland cement is another application where usage has increased in the past several years. Recent research results would indicate that large quantities of coal ash could also be effectively used for agriculture and land reclamation products. The use of coal ash for lightweight aggregate initially looked very promising; however, in the last few years its use has decreased. The estimated potential utilization of coal ash for selected applications has been compiled by the Aerospace Corporation and is presented in Table XVII.(2, 3, 6, 8, 10, 20, 27, 29, 32, 34, 37, 39, 41, 42, 43, 44)

TABLE XII

COMPARATIVE ASH UTILIZATION, 1966 THROUGH 1972 (2, 3, 27)

Produced (tons)	1966	1967	1968	1969	1970	1971	1972
Fly Ash	17, 123, 144	18, 409, 854	19, 813, 747	22, 304, 513	26, 538, 019	27, 751, 054	31, 808, 065
Bottom Ash	8, 065, 683	9, 131, 453	7, 259, 212	8, 042, 017	9, 890, 951	10, 058, 967	10, 672, 860
Boiler Slag	----------	----------	2, 554, 569	3, 020, 282	2, 801, 475	4, 970, 786	3, 781, 660
TOTAL	25, 188, 827	27, 541, 307	29, 627, 528	33, 366, 812	39, 230, 445	42, 780, 807	46, 262, 585
Total Utilized	3, 050, 669	3, 794, 714	5, 194, 016	5, 306, 764	5, 095, 659	8, 603, 720	7, 575, 503
Percent	12. 11%	13. 78%	17. 53%	15. 90%	13%	20%	16. 3%
Fly Ash	7. 9%	8. 2%	9. 6%	9. 6%	8. 13%	11. 7%	11. 4%
Bottom Ash	21. 0%	25. 0%	25. 0%	25. 0%	18. 63%	16. 03%	24. 3%
Boiler Slag	--------	--------	57. 8%	57. 8%	39. 06%	75. 21%	35. 3%

TABLE XIII

ASH UTILIZATION FOR 1972[27]
TONS

Applications	Fly Ash	Bottom Ash	Boiler Slag
I. Cement			
A. In type 1-P cement (As a pozzolan mixed with cement)	72,201	-----	-----
B. As a raw material for cement clinker	116,178	30,248	110,000
C. Partial replacement of cement			
1. concrete products (block etc.)	143,112	22,678	-----
2. structural concrete	301,689	-----	-----
3. mass concrete-dams	67,880		
II. Road base stabilization	153,629	24,648	4,683
III. Lightweight aggregate	133,901	23,521	-----
IV. Fill material for roads, construction, etc.	584,860	750,660	477,293
V. Filler in asphalt mix	139,937	14,634	43,431
VI. No cost removal from utility	1,495,156	814,336	1,235
VII. Miscellaneous	426,737	921,193	701,663
Oil well cementing	75,872	-----	-----
Mine fire control	-----	-----	-----
Mine subsidence control	-----	-----	-----
Unclassified	310,282	457,558	336,326

TABLE XII (cont.)

ASH UTILIZATION FOR 1972[27]
TONS

Application	Fly Ash	Bottom Ash	Boiler Slag
VII. Miscellaneous (cont)			
An abrasive for cleaning	------	------	------
Spontaneous combustion control	------	------	------
Highway bridges	------	------	------
Test caps	------	------	------
Refractory add mix	------	------	------
Insulating cement	------	------	------
Grouting	------	------	------
Snow sanding	------	------	------
Pipe coating	1,637	------	------
Foundaries			
sand	------	------	------
manufacturer products	12,000	------	------
Chemical products	465	------	------
Poz-O-Pac	------	------	------
Sewage treatment plants (filtration)	------	------	------
Substrate courses (heavy construction)	------	------	28,913
Ready mix			
Oil Well drilling			
Industrial testing			34,000
Vanadium recovery	581	1,301	------
Ice control	------	93,777	84,336
Outdoor school tracks			
Asphalt shingles	------	60,089	------
Sandblasting grit	------	20,754	120,337

TABLE XIII(concluded)

ASH UTILIZATION FOR 1972[27]
TONS

Application	Fly Ash	Bottom Ash	Boiler Slag
VII. Miscellaneous (cont)			
Dike repair and buildings	------	121,500	------
Drainage filter	------	------	------
Aggregate	------	139,716	40,738
Landfill	25,900	26,248	------
Agriculture	------	------	------
Dust control	------	250	------
Seal coating	------	------	300
Roofing Granules	------	------	46,255
Railroad base	------	------	10,358

TABLE XIV

KNOWN USES FOR ASH REMOVED FROM PLANT AT NO COST TO UTILITY IN 1972[27]

	TONS		
	Fly Ash	Bottom Ash	Boiler Slag
Anti-skid material	9,333	178,654	
Landfill	197,779	34,056	
Mine Fire Control	32,558		
Poz - O -Pac	4,000		
Vanadium Recovery		642	
Building Blocks and Fill Material		13,630	
Foundation			225
Cement Raw Material	55,972	3,000	
Mine Refuse Filler and Conditioner	2,070	49,788	
Lightweight Aggregate		770	
Agriculture Experiments	12		
TOTAL KNOWN USES - TONS	301,724	280,540	225

TABLE XV

PRODUCTION AND UTILIZATION OF ASH FROM HARD COAL (FLY ASH HEARTH ASH, MOLTEN ASH) IN 1971 (28)

Country	Production,[1] 1,000 tons	Commercial utilization, 1,000 tons													Production used, percent
		Cement (addition or replacement of hydraulic binder)	Cement kilns	Roads	Cellular concrete	Compacted concrete: Blocks	Compacted concrete: Prepared concrete	Dams	Light-weight aggregate	Bricks	Filler on construction sites	Miscellaneous	Total		
Europe:															
Austria	2.7	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp		NAp
Belgium[2]	603.9	NAp	NAp	146.1	5	2	NAp	NAp	5	73	18.2	17	226.3		44.2
Cyprus	NAp	NAp	NAp	NAp	NAp	NAp	2,050	NAp	NAp	NAp	NAp	NAp	NAp		NAp
Federal Republic of Germany	6,500	250	50	310	NAp	NAp	NAp	NAp	NAp	NAp	1,885	650	5,195		79.19
Finland	153	NAp	NAp	1	NAp	NAp	NAp	NAp	NAp	NAp	78	NAp	79		51.6
France	4,185	681	246	1,497	NAp	96	NAp	NAp	NAp	11	136	58	2,725		65.1
Greece	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp		NAp
Italy[3]	210	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp		NAp
Luxembourg	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp		NAp
Malta	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp		NAp
Netherlands	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp		NAp
Norway	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp		NAp
Poland	4,971	165	12	22	711	458	315	NAp	NAp	NAp	NAp	NAp	NAp		NAp
Portugal	[5]80	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	[4]	19	1,702		34.2
Romania	1,040	5	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp		NAp
Switzerland	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	1	6		.6
Turkey	200	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp		NAp
U.S.S.R.	31,600	150	NAp	NAp	50	90	NAp	NAp	NAp	40	NAp	120	450		1.4
United Kingdom	10,370	126	29	3,183	467	736	11	3	244	28	498	NAp	5,560		53.6
Total	59,915.6	1,377	337	5,159.1	1,233	1,382	2,376	3	249	152	2,615.2	865	15,748.3		26.7
United States of America	42,781	17	248	350	NAp	304	185	71	193	NAp	4,342	2,894	8,604		20.1
Grand total	102,702.6	1,394	585	5,509.1	1,233	1,686	2,561	74	442	152	6,957.2	3,759	24,352.3		23.9
Percent of total	NAp	5.7	2.4	22.6	5	6.9	10.5	0.3	1.8	0.6	28.6	15.6	100		NAp

NAp–Not applicable or not available.
[1] Total output of ash from pulverized-coal-fired boilers calculated on the basis of the ash content of the coal.
[2] Partial figures.
[3] Figures only for ENEL (Ente Nazionale per Energia Elettrica).
[4] Hearth ash used for leveling uneven ground is not recorded.
[5] Anthracite.

TABLE XVI

PRODUCTION AND UTILIZATION OF ASH FROM LIGNITE (FLY ASH, HEARTH ASH, MOLTEN ASH) IN 1971 (28)

Country	Production,[1] 1,000 tons	Commercial utilization, 1,000 tons												Production used, percent
		Cement (addition or replacement of hydraulic binder)	Cement kilns	Roads	Cellular concrete	Compacted concrete: Blocks	Compacted concrete: Prepared concrete	Dams	Lightweight aggregate	Bricks	Filler on construction sites	Miscellaneous	Total	
Europe:														
Austria	633	16.8	NAp	NAp	NAp	1.5	NAp	2.0	NAp	17.5	30.1	0.8	68.7	10.8
Belgium	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Cyprus	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Federal Republic of Germany	6,000	10	100	150	NAp	NAp	10	NAp	NAp	NAp	150	80	500	8.3
Finland	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
France	376	100	6	6	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	112	29.8
Greece	1,400	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Italy[2]	400	1	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	8	2	10	2.5
Luxembourg	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Malta	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Netherlands	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Norway	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Poland[3]	3,797	NAp	NAp	24	NAp	32	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Portugal	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	80	136	3.6
Romania	2,780	16	NAp	NAp	50	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Switzerland	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	2	NAp	18	86	3.1
Turkey	167	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
U.S.S.R.[3]	20,800	100	NAp	NAp	2	NAp	NAp	43	NAp	NAp	NAp	.3	43.3	25.9
United Kingdom	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp	110	NAp	490	762	3.4
Total	36,353	242.8	106	180	52	33.5	10	45	NAp	129.5	188.1	671.1	1,658.0	4.6
United States of America	449	NAp	NAp	15.6	NAp	NAp	2.2	NAp	NAp	NAp	NAp	.4	18.2	4.1
Grand total	36,802	242.8	106	195.6	52	33.5	12.2	45	NAp	129.5	188.1	671.5	1,676.2	4.6
Percent of total	NAp	14.5	6.3	11.7	3.1	2.0	0.7	2.7	NAp	7.7	11.2	40.1	100	NAp

NAp–Not applicable or not available.
[1] Total output of ash from pulverized-coal-fired boilers calculated on the basis of the ash content of the coal.
[2] Figures only for ENEL (Ente Nazionale per Energia Elettrica).
[3] Including bituminous shale.

TABLE XVII

ESTIMATED ASH UTILIZATION POTENTIAL [6]

Uses	Maximum Utilization Tech. Feasible	1970 Utilization	Estimated Utilization Current Conditions	Potential Improved Utilization
Fly ash concrete (structural, mass and concrete products)	10-15	0.54	3.5	6.0
Lightweight aggregate	13	0.21	0.5	3.0
Raw material for cement clinker	13	0.16	0.25	---
Bricks	10	----	----	----
Filler in bituminous products	1-2	0.13	0.75	---
Base stabilizer for roads AP*		0.11	0.3	>10.0
Agriculture and land recovery AP*		----	----	----
Control of mine subsidence and fires	> 1	0.01	0.75	> 1.0
Structural fill for roads construction sites, land reclamation, etc. AP*		0.32	0.6	---
Others	----	0.16	0.25	---
Total (million tons/year)		1.64	6.9	---

*AP - annual production

Effective utilization of coal ash requires that the ash materials satisfy the technical specifications for the application and be economically competitive. Transportation of the coal ash, to the site for its use, is a major factor of economic concern. Ideally, any production or utilization process should be located close to the source of raw material; that is at the powerplant. However, this is not always possible. Using trucks, fly ash can be removed from a utility at an average cost of $0.06 per ton/mile (20 to 30 tons per truck). For short hauls, an extra charge of $1.00 for loading and $1.00 for unloading will be incurred. Furthermore, trucks can be expected to operate with maximum economies only to a range of about 150 miles. This enables the trucker to get to his destination, unload and return in the same day, avoiding any overtime for stay-over.

When fly ash is used in cement and concrete applications, it is competing with the natural raw materials and cement industry products and its utilization is hampered by the fact that freight rates for shipping fly ash are 20% higher then for the natural products. This is because of tariffs that give an advantage to natural or virgin materials over secondary materials.

The literature describing current coal ash applications as well as research and pilot studies of potential applications is quite extensive. A compilation of the pertinent literature for each of the various applications and potential applications is presented in Table XVIII.

It is anticipated that significant markets of tomorrow will be generated from the more imaginative research and pilot programs currently under investigation. Initial evaluation would suggest that among the current applications greater coal ash utilization should be achieved in the production of fly ash concrete and portland cement clinker, over 120 million tons of raw materials are utilized in the annual production of cement products, indicating a very large potential market for coal ash.

TABLE XVIII

BIBLIOGRAPHY OF COAL ASH APPLICATIONS

Application	Reference
I. Cement and Concrete	
A. As a pozzalan	7, 11, 12, 33, 50, 51
B. Mixed with Portland Cement	3, 32, 33, 52, 53, 54
C. Partial Replacement of Portland Cement	3, 10, 12, 32, 33
1. concrete products (block, etc.)	48, 55
2. structural concrete	15, 31, 56
3. massive concrete	34, 56
D. As a Raw Material for Cement Clinker	3, 6, 11
II. Lightweight Aggregate	3, 5, 10, 12, 16, 22, 50, 56
III. Road Base and Soil Stabilization	3, 5, 10, 11, 12, 20, 22, 30 37, 39, 56, 66
IV. Fill for Roads and Other Construction (embankments, etc.)	3, 10, 11, 19, 20, 35, 36, 56, 57
V. Fill for Asphalt	3, 10, 20, 56
VI. Research and Pilot Applications	29
A. Brick	3, 10, 11, 49, 56, 58, 59, 73, 74, 75, 77, 80, 81
B. Mineral Wool	11, 12, 22, 24, 72, 76, 78
C. Control of Oil Spills	3, 11
D. Aerated or Gas Concrete Block	3, 10, 11, 12, 54
E. Metal Oxide Recovery	10, 40
F. Anti-Skid Filler for Tires	11, 20
G. Ice Control	12
H. Anti-Skid Filler for Asphalt Road Paving	3, 11, 20
I. Use of Cenospheres	
1. replace glass microspheres	11, 21
2. oil well cement	60
3. catalyst for petroleum	12
4. coolant	12
5. thermal insulation	3, 21
J. Mining	
1. control of mine fires	10, 11, 12
2. control of acid mine drainage	3, 10, 11, 12, 22, 56
3. reduction of mine subsidence (fill for abandoned mines)	11, 12, 49, 61
4. recovery of mine spoilage	10, 12, 17, 42, 47, 56

TABLE XVIII
(concluded)

Application	Reference
K. Paving Material from Mixture of Ash and Sulfate Sludge	10, 38, 62, 63
L. Treating Polluted Water	11, 12, 13, 22, 56, 64, 65
M. Aid in Treatment of Sludges	5, 56, 64, 67, 68, 69
N. Agricultural	11, 13, 41, 42, 43, 46, 70, 71
O. Sanitary Land Fill Cover	44

REFERENCES

1. Faber, J.H. and Meikle, P.G., "Use and Disposal of Fly Ash", presented at the Association of Rural Electric Generating Cooperatives, Annual Plant Operators Conference, Lexington, Ky., June, 1970.

2. Brackett, C.E., "Production and Utilization of Ash in the United States", Presented at the Third International Ash Utilization Symposium, Pittsburgh, Pa., March, 1973.

3. Faber, J.H., et al., "Fly Ash Utilization", IC8488, Bureau of Mines, U.S. Department of the Interior, 1970.

4. Cockrell, C.F., et al., "Production of Fly Ash-Based Structural Materials", Office of Coal Research, R. and D. Report No. 69, Contract No. 14-01-0001-488, U.S. Department of the Interior, Washington, D.C., 1972.

5. Gartrell, F.E., Barber, J.C., "Environmental Protection - TVA Experience", Journal of the Sanitary Engineering,Division Proceedings of the American Society of Civil Engineers, SAL 1321-1333, December, 1970.

6. Rossoff, J., et al., "Technical and Economic Factors Associated with Fly Ash Utilization", Report TOR-0059 (6781)-1, Office of Corporate Planning, The Aerospace Corporation, El Segundo, California, July, 1971.

7. Hyland, E.J., "Factors Affecting Pozzolan Marketing", Presented at the Third International Ash Utilization Symposium, Pittsburgh, Pa., March, 1973.

8. Capp, J.P., and Spencer, J.D., "Fly Ash Utilization - A Summary of Applications and Technology", Information Circular 8433, U.S. Department of the Interior, Bureau of Mines, 1970.

9. Anonymous, "Utility Directory, Keystone Coal Industry Manual," 1971.

10. Covey, J.N. and Faber, J.H., "Ash Utilization - Views on Growth Industry", Proceedings of the Third Mineral Waste Utilization Symposium, U.S. Bureau of Mines and Illinois Institute of Technology Research Institute, March, 1972.

11. Anonymous, "Ash at Work", Published by the National Ash Association, Washington, D. C., (Vol. I, 1969; Vol. IV, 1972).

12. Faber, J.H. and Meikle, P.G., "Ash Utilization Techniques Present and Future", Proceedings of the Second Mineral Waste Utilization Symposium, U.S. Bureau of Mines and Illinois Institute of Technology Research Institute, March, 1970.

13. Anonymous, "Fly Ash Still Piling-Up", Chemical Engineering, April 20, 1970.

14. Rohrman, F.A., "Analyzing the Effect of Fly Ash on Water Pollution", Power, August, 1971.

15. Rehsi, S.S., "Studies on Indian Fly Ashes and their Use in Structural Concrete", Presented at the Third International Ash Utilization Symposium, Pittsburgh, Pa., March, 1973.

16. Minnick, J.L. and Corson, W.H., "Fly Ash: Now Meets Lightweight Aggregate Specifications", Brick and Clay Record, April, 1965.

17. Adams, L.M., et al., "Reclamation of Acidic Coal-Mine Spoil with Fly Ash", Bureau of Mines, Report of Investigations 7504, U.S. Department of the Interior, April, 1971.

18. Humphreys, K.K. and Lawrence, W.F., "Production of Mineral Wool Insulating Fibers from Coal Ash Slag and other Derived Waste Materials", Proceedings of the Second Mineral Waste Utilization Symposium, U.S. Bureau of Mines and Illinois Institute of Technology Research Institute, March, 1970.

19. Gray, D.H., and Lin, Y.K., "Engineering Properties of Compacted Fly Ash", Journal of the Soil Mechanics and Foundations Division, Proceedings of the American Society of Civil Engineers, SM4, April, 1972, pp. 361-380.

20. Moulton, L., "Bottom Ash and Boiler Slag", Presented at the Third International Ash Utilization Symposium, Pittsburgh, Pa., March, 1973.

21. Pedlow, J.W., "Cenospheres", Ibid.

22. Anonymous, "Sulfur Oxide Control and Fly Ash Utilization - A Progress Report", National Ash Association, Report No. 1-71, Washington, D.C.

23. Cockrell, C. F., et al., "The Application of Flotation for Recovery of Calcium Constituents from Limestone Modified Fly Ash", Report No. 59, Coal Research Bureau, West Virginia University, Morgantown, W. Va.

24. Cockrell, C. F., et al., "Characterization and Utilization Studies on Limestone Modified Fly Ash", Report No. 60, Coal Research Bureau, West Virginia University, Morgantown, W. Va.

25. Anonymous, "Office of Coal Research Annual Report", Office of Coal Research, U.S. Department of the Interior, 1972.

26. Miller, C. L., U.S. Dept. of the Interior, Office of Coal Research, Washington, D. C., Private Communication, March, 1973.

27. Brackett, C. E., Vice President, Southern Electric Generating Company, Private Communication, March, 1973.

28. Rechert, W. W., "Activities of the Economic Commission for Europe in the Field of Ash Utilization", Presented at the Third International Ash Utilization Symposium, Pittsburgh, Pa., March, 1973.

29. Slonaker, J. E. and Leonard, J. W., "Review of Current Research on Coal Ash in the United States", Ibid.

30. Minnick, J. L., "Multiple By-Product Utilization", Ibid.

31. Guida, K., "The Uses of Fly Ash in a Ferro-Cement Mix Design", Ibid.

32. Mielenz, R. C., "Specifications and Methods of Using Fly Ash In Portland-Cement Concrete", Ibid.

33. Tonewell, C. E., "Portland-Pozzolan Cement", Ibid.

34. Elfert, R. J., "Bureau of Reclamation Experiences with Fly Ash and Other Pozzolans in Concrete", Ibid.

35. Smith, P. H., "Large Tonnage Uses of PFA in England and Other European Countries", Ibid.

36. Lamb, W. D., "Ash Disposal in Dams, Mounds, Structural Fills, and Retaining Walls", Ibid.

37. Barenberg, E. J., "Utilization of Ash in Stabilized Base Construction", Ibid.

38. Brink, R.H., "Use of Waste Sulfate on Transpo '72 Parking Lot", Ibid.

39. Blocker, M.V., et al., "Marketing Power Plant Aggregates as Road Base Material", Ibid.

40. Nowak, Z.N.I., "Iron and Alumina Extraction from Power Plant Fly Ash in Poland", Ibid.

41. Barber, E.G., "Land Reclamation and Environmental Benefits of Ash Utilization", Ibid.

42. Capp, J.P., and Gillmore, D.W., "Soil-Making Potential of Power Plant Fly Ash in Mixed-Land Reclamation", Ibid.

43. Martens, D.C., and Plank, C.I., "Basic Soil Benefits from Ash Utilization", Ibid.

44. Zaltaman, R., "Sanitary Reclamation of Refuse Dumps", Ibid.

45. Jackson, J., "Total Utilization of Fly Ash", Proceedings of the Third Mineral Waste Utilization Symposium, U.S. Bureau of Mines and Illinois Institute of Technology Research Institute March, 1972.

46. Amos, D.F., and Wright, J.D., "The Effect of Fly Ash on Soil Physical Characteristics", Ibid.

47. Adams, L.M., et al., "Coal Mine Spoil and Refuse Bank Reclamation with Powerplant Fly Ash", Ibid.

48. Hyland, E.J., "Practical Use of Fly Ash in Concrete", Construction Specifier, March, 1971.

49. Shafer, H.E., "Fly Ash Brick Could Cut Fuel Costs 2 cents/million BTU", Electric Word, January, 1967.

50. Minnick, J.L., "Structural Compositions Prepared From Inorganic Waste Products", Presented at the Annual Meeting of the American Association of State Highway Officials, Miami Beach, Florida, December, 1971.

51. Barenberg, E. J., "Lime-Fly Ash-Aggregate Mixtures in Pavement Construction", NAA Report- Ash at Work- Process and Technical Data - National Ash Association Inc., Washington, D. C.

52. Kalousek, G. L., et al., "Concrete for Long-Time Service in Sulfate Environment", Cement and Concrete Research, Vol. 2, (79-89), 1972.

53. Smith, P. H., "Basemix Cement-Bound PFA", Presented at the National Ash Association Annual Technical Meeting, November, 1971.

54. Stearn, E. W., "Fly Ash Stimulates Symposium with Versatility and Abundance", Ro Products, May, 1970.

55. Hester, J. A., "Study of Fly Ash as a Material for Use in Concrete", Alabama Highway Research, HPR, Report No. 51, Alabama Highway Department, June, 1970.

56. Anonymous, "Fly Ash Utilization Climbing Steadily", Environmental Science and Technology, March, 1970.

57. DiGioria, A. M., and Nuzzo, W. L., "Fly Ash as a Structural Fill", Presented at the ASME-IEEE Joint Power Generation Conference - Preprint JPG-70-9, September, 1970.

58. Raymond, S., Smith, P. H., "Shear Strength, Settlement and Compaction Characteristics of Pulverised Fuel Ash", Civil Engineering and Public Works Review, 61, (722), 1107-1113, September, 1966.

59. Anonymous, "Putting Fly Ash to Work", Coal Age, February, 1971.

60. Bierderman, E. W., "Lightweight Cements for Oil Wells", U.S. Patent 3,669,701 June 13, 1972.

61. Murphy, E. M., et al., "Use of Fly Ash for Remote Filling of Underground Cavities and Passageways", Bureau of Mines Report of Investigations 7504, U.S. Department of the Interior, April, 1971.

62. Anonymous, "Transpo '72 Parking Lot Paved with Experimental Waste Mix", Roads and Streets, June, 1972.

63. Anonymous, "Pavement Made of Industrial Wastes, A Highlight at Transportation Show", Engineering News Record, April 6, 1972.

64. Eye, J.D., and Basu, T.K., "The Use of Fly Ash in Waste Water Treatment and Sludge Conditioning", Journal WPCF, 42, (5) Part 2, R125-R135, May, 1970.

65. Anonymous, "Air Pollutant Cleans a Lake", The American City, January, 1969.

66. Gray, D.H., "The Properties of Compacted Sewage Ash", Journal of the Soil Mechanics Division, Proceedings of the American Society of Civil Engineers, SMZ, March, 1970.

67. Moehle, F.W., "Fly Ash Aids in Sludge Disposal", Environmental Science and Technology, 1, (5) 374-379, 1967.

68. Tenney, M.W., and Cole, T.F., "The Use of Fly Ash in Conditioning Biological Sludges for Vacuum Filtration", Journal WPCF, 40, (8) Part 2, R281-R301, August, 1968.

69. Gerlich, J.W., "Fly Ash as a Filter Aid", Power Engineering, January, 1970.

70. Mulford, F.R., Martens, D.C., "Response of Alfalfa to Boron in Fly Ash", Soil Science Society of America Proceedings, 35 (2), March-April, 1971.

71. Martens, D.C., "Availability of Plant Nutrients in Fly Ash", Compost Science, 12 (6), November-December, 1971.

72. Humphrey, K.K., et al., "A Promising Possibility: Production of Mineral Wool from Coal Ash Sludge", Report No. 20, Coal Research Bureau - West Virginia University, Morgantown, W.Va.

73. Humphrey, K.K., et al., "Status Report on Bricks from Fly Ash", Report No. 29, Coal Research Bureau- West Virginia University, Morgantown, W.Va.

74. Shafer, H.E., et al., "A New and Low Cost Method for Making Structural Materials from Problem Fly Ashes and from Fly Ashes Likely to Originate from Certain Potential Air Pollution Control Processes", Report No. 34, Coal Research Bureau- West Virginia University, Morgantown, W.Va.

75. Humphreys, K.K., "An Economic Evaluation of the WVU-OCR Process for Producing Fly Ash- Based Structural Materials", Report No. 36, Coal Research Bureau- West Virginia University, Morgantown, W.Va.

76. Cockrell, C. F., et al., "Exploratory Studies on New Product and Process Potential of Power Plant Wastes Originating from Limestone Based Air Pollution Control Processes", Report No. 39, Coal Research Bureau - West Virginia University, Morgantown, W. Va.

77. Cockrell, C. F., et al., A Technical Evaluation of the WVU-OCR Process for Producing Fly Ash-Based Structural Materials", Report No. 40, Coal Research Bureau - West Virginia University, Morgantown, W. Va.

78. Humphreys, K. K., et al., "Production of Mineral Wool Insulating Fibers from Coal Ash Slag and Other Coal Derived Waste Materials", Report No. 53, Coal Research Bureau - West Virginia University, Morgantown, W. Va.

79. Muter, R. B., et al., "Application of Thermogravimetric Analysis to a Study of the Degree of Carbonation and Emulsion Addition During Agglomerate Flotation of Limestone Modified Fly Ash", Report No. 54, Coal Research Bureau-West Virginia University, Morgantown, W. Va.

80. Humphreys, K. K., et al., "Economic Factors Affecting the Production of Brick, Block, and Other Structural Products from Fly Ash", Report No. 55, Coal Research Bureau - West Virginia University, Morgantown, W. Va.

81. Cockrell, C. F., et al., "Application of Simplex Sum Evolutionary Operation to the Utilization of Coal Ash for Structural Products", Report No. 58, Coal Research Bureau - West Virginia University, Morgantown, W. Va.

82. Abernathy, R. F., et al., "Major Ash Constituents in U.S. Coals", RI-7240, Bureau of Mines, U.S. Department of the Interior, 1969.

APPENDIX I

1970 Regional Fuel Use By Selected Electric Utilities With Projected Use For 1971 Through 1975 and 1980 (9)

(Thousands of Coal Equivalent Tons)

	1970	1971	1972	1973	1974	1975	1980
NEW ENGLAND							
Connecticut							
Connecticut Lt. & Power Co.							
Coal	2,003	1,110	0	0	0	0	—
Oil	525	1,640	2,800	3,400	3,000	3,000	—
Hartford Elec. Lt. Co.							
Coal	100	8	0	0	0	—	—
Oil	1,750	1,620	1,500	1,580	1,500	—	—
Gas	8	4	2	0	0	—	—
United Illuminating Co.							
Oil	2,520	1,800	1,770	1,910	1,950	2,720	—
Wallingford Dept. Pub. Util.							
Coal	20	20	20	20	20	20	20
Maine							
Bangor Hydro-Electric							
Oil	156	106	106	106	106	106	106
Massachusetts							
Fitchburg Gas & Elec. Lt. Co.							
Oil	104	104	5	5	5	5	0
Gas	26	26	15	15	15	15	10
Holyoke Water Power Co.							
Coal	146	—	—	—	—	—	—
Oil	290	440	250	250	240	—	—
Montaup Elec. Co.							
Oil	750	750	750	750	750	750	—
New England Gas & Elec. Assn.							
Coal	3	0	0	0	0	0	0
Oil	1,250	1,590	1,527	1,492	1,460	1,950	3,000
Gas	138	157	154	152	150	150	150
Western Massachusetts Elec. Co.							
Coal	362	63	—	—	—	—	—
Oil	310	420	350	400	300	—	—
New Hampshire							
Public Serv. Co. of New Hampshire							
Coal	1,041	1,049	1,025	1,015	935	1,013	1,000
Oil	675	698	631	525	852	1,333	2,000
Rhode Island							
Blackstone Valley Elec. Co.							
Oil	39	18	18	16	9	9	1
Gas	4	7	7	7	5	5	5
MID-ATLANTIC							
New Jersey							
Jersey Central Power & Lt. Co.							
Coal	10	0	0	0	0	0	0
Oil	1,043	1,138	1,156	1,095	1,037	982	930
Gas	160	116	67	59	59	59	59
New Jersey Pwr. & Lt. Co.							
Coal	266	22	0	0	0	0	0
Oil	3	251	341	323	306	280	275
Gas	96	104	20	20	20	20	20
Public Serv. Elec. & Gas							
Coal	3,694	3,876	4,014	3,882	4,096	3,720	3,393
Oil	7,345	7,680	7,004	5,211	6,014	5,985	5,304
Gas	1,365	1,200	800	400	400	1,200	4,423
Vineland Electric Util.							
Coal	65	50	50	50	—	—	—
Oil	90	120	135	150	—	—	—

	1970	1971	1972	1973	1974	1975	1980
New York							
Central Hudson Gas & Elec.							
Coal	750	88	—	—	—	—	—
Oil	354	1,343	1,442	1,899	2,765	2,765	3,266
Gas	105	15	15	30	30	30	30
Con Edison Co. of N.Y. Inc.							
Coal	2,688	1,460	230	—	—	—	—
Oil	9,912	10,121	10,321	10,453	8,995	9,179	10,047
Gas	3,899	2,760	2,622	2,418	2,231	2,142	1,737
New York State Elec. & Gas Corp.							
Coal	3,250	3,390	3,103	3,050	3,175	3,298	—
Orange & Rockland Util. Inc.							
Coal	124	290	—	—	—	—	—
Oil	485	330	683	1,358	1,554	—	—
Gas	496	379	319	320	291	—	—
Rochester Gas & Elec. Corp.							
Coal	1,100	958	800	897	800	800	800
Oil	22	11	126	146	142	162	200
Gas	13	30	31	32	32	32	35
Pennsylvania							
Allegheny Power Service Corp.							
West Penn Power							
Monongahela Power							
Potomac Edison							
Coal	10,185	10,400	11,500	12,300	—	—	—
Duquesne Light Co.							
Coal	4,977	4,933	5,139	4,966	4,244	4,178	—
Oil	6	6	6	6	6	6	—
Metropolitan Edison Co.							
Coal	1,859	—	—	—	—	—	—
Pennsylvania Pwr. & Lt. Co.							
Coal	5,807	6,266	7,055	6,739	7,183	—	—
Oil	77	59	44	45	73	—	—
Pennsylvania State Univ.							
Coal	70	75	75	75	75	70	70
Oil	1	1	2	3	4	6	9
Gas	6	6	7	7	10	20	40
Philadelphia Elec. Co.							
Coal*	2,825	3,757	3,929	3,970	4,010	3,988	3,500
Oil*	5,865	5,996	5,978	5,515	5,375	4,542	2,800
Gas	279	127	400	346	251	104	0

* Includes share of Jointly owned Plants.

	1970	1971	1972	1973	1974	1975	1980
EAST NORTH CENTRAL							
Illinois							
Central Illinois Lt. Co.							
Coal	1,748	1,751	1,945	2,186	2,186	2,211	3,400
Gas	107	122	172	183	200	200	200
Central Illinois Pub. Serv. Co.							
Coal	2,740	2,745	3,799	3,666	3,550	3,550	5,350
Electric Energy Inc.							
Coal	3,440	3,400	3,400	3,400	3,400	3,400	3,400
Illinois Power Co.							
Coal	3,882	4,846	4,975	5,120	5,197	5,866	8,930
Oil	5	5	5	240	388	375	341
Gas	600	404	200	5	5	5	5
Rochelle Munic. Util.							
Coal	41	43	45	47	49	52	273
Oil	10	10	11	11	12	13	66
Gas	19	40	42	44	46	49	256
Springfield Wt., Lt. & Pwr. Dept.							
Coal	540	580	620	670	700	750	1,100
Oil	3	4	4	4	6	6	—

APPENDIX I (Continued)

	1970	1971	1972	1973	1974	1975	1980
Wakefield, Village of							
Coal	21	21	21	21	—	—	—
Gas	28	31	35	38	—	—	—
Indiana							
Crawfordsville Elec. Lt. & Pwr.							
Coal	90	90	90	90	90	90	90
Frankfort Lt. & Pwr.							
Coal	75	80	85	85	85	—	—
Oil	2	3	5	5	3	—	—
Indiana-Kentucky Elec. Corp.							
Coal	4,039	4,224	—	—	—	—	—
Indiana & Michigan Elec. Co.							
Coal	4,740	4,148	—	—	—	—	—
Indianapolis Pwr. & Lt. Co.							
Coal	3,678	3,522	3,636	4,313	4,596	4,542	6,211
Northern Indiana Pub. Ser. Co.							
Coal	2,626	3,460	3,460	4,310	4,360	5,330	—
Gas	708	72	72	72	72	72	72
Public Service Indiana							
Coal	5,322	5,694	6,488	6,976	6,895	7,832	14,000
Oil	62	62	77	88	88	93	103
Richmond Pwr. & Lt. Co.							
Coal	142	142	150	230	250	260	—
Michigan							
City of Detroit Pub. Lt. Comm.							
Coal	309	325	340	235	250	265	—
Gas	—	—	—	137	137	137	—
Coldwater Bd. Pub. Util.							
Coal	31	32	32	32	32	60	60
Consumers Power Co.							
Coal	6,938	6,746	5,952	5,620	5,891	6,189	5,500
Oil	32	55	329	407	451	1,320	1,381
Gas	441	508	408	344	352	311	237
Detroit Edison Co.							
Coal	11,537	12,363	14,028	15,257	17,554	16,551	14,026
Oil	765	644	588	679	616	200	3
Gas	631	466	413	509	428	69	0
Holland Bd. Pub. Works							
Coal	60	65	70	75	80	85	100
Gas	75	78	82	86	91	95	164
Northern Michigan Elec. Coop.							
Coal	131	145	150	155	—	—	—
Oil	1	1	1	1	—	—	—
Traverse City Lt. & Pwr.							
Coal	53	56	60	64	69	74	100
Gas	5	5	6	6	7	8	10
Upper Peninsula Power & Gener. Co.							
Coal	621	645	645	645	1,121	1,188	1,488
Gas	39	28	28	28	28	28	28
Ohio							
Cardinal Operating Co.							
Coal	3,020	2,773	—	—	—	—	—
Plant operated jointly for Ohio Pwr. Co. and Buckeye Pwr. Inc.							
Celina Munic. Util.							
Coal	50	50	50	50	—	—	—
Cincinnati Gas & Elec. Co.							
Coal	3,852	3,956	4,496	5,013	5,451	6,310	6,319
Oil	20	452	403	206	200	116	116
Gas	361	348	215	110	179	69	51
Cleveland Elec. Illum. Co.							
Coal	6,075	6,378	6,586	6,916	6,990	7,292	—
Oil	11	9	9	264	298	224	—
Columbus & Southern Ohio Elec.							
Coal	2,572	2,286	2,595	3,851	4,109	4,305	4,500
Oil	16	55	32	26	29	29	29
Gas	47	34	55	33	40	40	40
Dayton Pwr. & Lt. Co.							
Coal	2,228	4,066	6,216	6,043	7,661	8,036	10,500
Oil	35	13	6	12	16	14	30
Gas	76	32	7	16	20	33	70
Girard Munic. Lt. & Pwr.							
Coal	39	41	43	46	48	52	66
Oil	1	1	1	1	1	1	1
Hamilton Dept. Pub. Util.							
Coal	160	60	80	80	80	80	—
Oil	2	5	5	5	5	5	—
Gas	24	45	45	45	45	45	—
Ohio Edison Co.							
Coal	6,786	7,257	—	—	—	—	—
Ohio Power Co.							
Coal	7,908	10,982	—	—	—	—	—
Ohio Valley Elec. Corp.							
Coal	2,922	3,092	—	—	—	—	—
Orrville Munic. Util.							
Coal	60	66	72	80	88	—	—
Piqua Munic. Pwr. Sys.							
Coal	99	100	—	—	—	—	—
Oil	1	3	—	—	—	—	—
Shelby Munic. Lt. & Pwr.							
Coal	41	44	46	49	52	54	—
Wisconsin							
Dairyland Pwr. Coop.							
Coal	1,455	1,400	1,400	1,500	1,500	1,500	2,000
Madison Gas & Elec. Co.							
Coal	184	181	161	174	240	213	205
Oil	3	—	—	—	—	—	—
Gas	259	—	—	—	—	—	—
Marshfield Elec. & Wt. Dept.							
Coal	82	90	100	112	125	140	160
Menasha Elec. & Wt. Util.							
Coal	70	74	79	85	85	85	110
Richland Center Munic. Elec. Util.							
Coal	15	17	18	20	21	23	30
Wisconsin Elec. Pwr. Co.							
Coal	5,300	5,300	4,600	4,600	4,600	4,700	7,500
Oil	275	150	100	100	100	100	150
Gas	200	225	250	275	275	275	300
Wisconsin Pwr. & Lt. Co.							
Coal	1,986	2,281	2,460	2,125	2,300	3,400	5,880
Gas	133	130	130	130	130	130	130
Wisconsin Pub. Serv. Corp.							
Coal	1,385	1,443	1,633	2,104	2,242	2,305	2,741
Oil	2	10	16	16	22	33	36
Gas	233	239	242	156	135	99	114

WEST NORTH CENTRAL

Iowa

Cedar Falls Munic. Util.							
Coal	30	37	51	70	88	101	185
Oil	2	5	5	5	1	1	1
Gas	54	40	40	40	40	40	40
Corn Belt Power Coop.							
Coal	57	62	66	70	50	53	80
Gas	121	114	123	130	93	93	148
Eastern Iowa Lt. & Pwr. Coop.							
Coal	80	90	100	100	110	110	120
Gas	60	50	50	50	50	50	50
Interstate Power Co.							
Coal	760	940	1,020	1,110	1,139	1,218	1,686
Oil	117	136	230	255	290	328	300
Gas	359	137	182	162	159	120	90
Iowa Elec. Lt. & Pwr. Co.							
Coal	850	980	900	900	400	460	—
Gas	449	400	390	390	180	180	—
Iowa Illinois Gas & Elec. Co.							
Coal	438	425	300	300	—	—	—
Oil	2	0	0	0	—	—	—
Gas	806	530	530	530	—	—	—
Iowa Power & Light							
Coal	678	813	830	665	620	700	—
Oil	1	1	1	1	1	1	—
Gas	771	715	720	600	550	600	—
Iowa Pub. Serv. Co.							
Coal	325	394	1,023	1,266	974	1,049	1,271
Oil	1	10	10	10	10	10	10
Gas	627	571	417	314	146	136	56
Pella Munic. Pwr. & Lt.							
Coal	40	43	47	50	54	59	86
Gas	1	2	4	4	4	4	5

APPENDIX I (Continued)

	1970	1971	1972	1973	1974	1975	1980
Kansas							
Kansas City Bd. Pub. Util.							
Coal	240	285	300	325	350	375	500
Gas	480	570	600	650	700	750	1,000
Kansas Gas & Elec. Co.							
Coal	—	1	1	855	950	1,045	—
Oil	17	6	6	3	3	97	—
Gas	2,995	2,580	2,700	1,995	2,110	2,160	—
Kansas Power & Lt. Co.							
Coal	158	400	500	600	700	800	2,000
Oil	40	50	60	60	70	80	100
Gas	1,679	1,700	1,760	1,750	1,770	1,820	1,800
Ottawa Wt. & Lt. Dept.							
Gas	25	28	29	31	33	—	—
Wellington Munic. Util.							
Oil	0	1	1	1	1	1	1
Gas	28	30	32	33	34	36	46
Western Pwr. Div. Cent. Tel. & Util.							
Oil	12	12	13	14	14	15	—
Gas	639	661	703	705	709	756	—
Minnesota							
Fairmont Pub. Util. Comm.							
Coal	12	18	18	—	—	—	—
Oil	2	2	8	—	—	—	—
Gas	176	176	176	—	—	—	—
Hibbing Pub. Util. Comm.							
Coal	75	120	—	—	—	—	—
Gas	16	—	—	—	—	—	—
Litchfield Munic. Pub. Util.							
Coal	4	5	5	6	6	—	—
Gas	4	4	4	4	4	—	—
Minnesota Power & Lt. Co.							
Coal	1,300	1,492	1,500	2,000	2,900	2,900	2,900
Pet. Coke	93	3	3	—	—	—	—
Gas	17	0	0	0	0	0	0
Northern States Pwr. Co.							
Coal	3,990	4,000	3,800	4,000	3,800	3,900	8,000
Oil	198	105	175	200	240	330	400
Gas	1,990	1,520	1,220	1,140	1,000	960	500
Otter Trail Pwr. Co.							
Coal	853	853	853	853	853	2,043	3,293
Rochester Public Util. Dept.							
Coal	75	82	90	100	110	120	—
Gas	75	82	90	100	110	120	—
Springfield Pub. Util. Comm.							
Coal	3	3	4	—	—	—	—
Gas	7	8	8	—	—	—	—
Unlimited Power Assn.							
Coal	900	900	900	900	900	900	900
Missouri							
Arkansas-Missouri Pwr. Co.							
Gas	19	19	19	19	19	19	19
Columbia Wt. & Lt. Dept.							
Coal	99	83	92	95	106	117	0
Gas	41	75	83	85	95	104	350
Independence Pwr. & Lt.							
Coal	25	33	46	65	87	114	242
Oil	4	4	12	12	12	12	12
Gas	168	182	186	195	204	212	295
Kansas City Pwr. & Lt. Co.							
Coal	2,724	2,654	3,077	3,699	4,020	4,277	—
Oil	4	4	34	39	39	69	—
Gas	1,060	939	549	312	312	312	—
Macon Munic. Util.							
Coal	1	1	—	—	—	—	—
Missouri Pub. Ser. Co.							
Coal	700	850	900	900	900	1,145	1,600
Gas	100	50	50	50	50	100	100
Springfield City Util.							
Coal	40	60	90	120	160	190	400
Gas	400	400	400	400	400	400	450
St. Joseph Lt. & Pwr. Co.							
Coal	41	58	59	124	189	264	503
Oil	4	6	7	7	10	14	25
Gas	528	576	598	523	465	417	354
Union Electric Co.							
Coal	6,624	7,960[1]	9,320[1]	9,700[1]	10,160[1]	11,380[1]	15,220[1]
Oil	196	—	—	—	—	—	—
Gas	492	—	—	—	—	—	—

[1] Oil & Gas use dependent on competitive situation.

	1970	1971	1972	1973	1974	1975	1980
Nebraska							
Central Nebraska Pub. Pwr. & Irrig.							
Oil	25	45	65	85	105	125	150
Gas	230	205	180	155	130	105	50
Fremont Dept. of Util.							
Coal	27	32	47	57	63	65	150
Gas	100	100	95	95	100	110	110
Grand Island Util.							
Oil	7	7	8	8	9	10	14
Gas	93	100	108	117	126	137	201
Nebraska Public Pwr. Dist.							
Coal	339	380	380	380	250	250	1,250
Oil	14	14	14	14	14	14	14
Gas	590	549	549	474	474	474	474
Omaha Public Power Dist.							
Coal	650	930	916	233	253	286	297
Oil	9	9	9	9	9	9	9
Gas	768	623	550	313	304	353	267
North Dakota							
Basin Elec. Pwr. Coop.							
Coal	1,324	1,200	1,200	1,200	1,200	3,750	3,750
Oil	30	30	30	30	30	45	45
Minnkota Pwr. Coop. Inc.							
Coal	135	1,140	1,250	1,250	1,250	1,250	1,250
Oil	3	1	1	1	1	1	1
South Dakota							
Northwestern Pub. Serv. Co.							
Coal	60	60	60	60	60	200	—
Gas	40	40	40	40	40	40	—

SOUTH ATLANTIC

Delaware							
Delmarva Pwr. & Lt. Co. (Northern Div.)							
Coal	682	682	0	0	0	0	0
Oil	332	443	1,068	1,837	2,222	2,222	2,222
Gas	56	56	56	56	56	56	56
Delmarva Pwr. & Lt. Co. (Sou. Div.)							
Coal	782	882	968	896	815	—	—
Oil	10	10	10	10	10	—	—
Dover, City of							
Coal	65	69	73	78	82	87	93
Oil	1	1	1	1	171	—	—
Gas	22	23	25	26	28	29	31
District of Columbia							
Potomac Elec. Pwr. Co.							
Coal	4,766	4,495	4,899	4,974	4,980	5,020	—
Oil	1,788	1,586	1,997	2,091	2,194	2,263	—
Florida							
Florida Power Corp.							
Coal	1,035	810	—	—	—	—	—
Oil	2,303	2,808	4,260	2,451	3,268	3,779	6,136
Gas	1,059	837	841	839	839	839	—
Gulf Power Co.							
Coal	1,544	1,628	1,961	2,993	—	—	—
Oil	37	40	54	47	—	—	—
Gas	776	970	349	147	—	—	—
Jacksonville Elec. Author.							
Oil	1,632	1,800	1,980	2,178	2,396	2,632	4,240
Lakeland Dept. of Elec. & Wt. Util.							
Oil	99	160	176	190	208	227	515
Gas	235	160	176	190	208	227	515
Georgia							
Georgia Power Co.							
Coal	9,700	9,700	11,200	11,400	12,700	15,200	—
Oil	1	1	1	1	2	2	—
Gas	2,060	1,880	1,792	1,200	1,200	748	—

APPENDIX I (Continued)

	1970	1971	1972	1973	1974	1975	1980
Maryland							
Baltimore Gas & Elec. Co.							
Coal	3,125	3,003	2,948	1,559	1,618	1,272	—
Oil	2,045	1,888	2,405	3,200	3,349	2,121	—
Gas	43	43	43	43	43	43	—
Delmarva Pwr. & Lt. Co. of Maryland							
Coal	210	170	—	—	—	—	—
Oil	25	160	190	200	200	—	—
North Carolina							
Carolina Pwr. & Lt. Co.							
Coal	5,816	5,378	6,097	6,448	6,220	6,566	—
Duke Power							
Coal	13,003	12,751	12,630	11,174	—	—	—
Oil	374	165	140	16	—	—	—
Gas	524	914	761	222	—	—	—
University of North Carolina							
Coal	27	15	15	15	15	15	15
Oil	0	15	18	20	23	26	40
Gas	26	27	27	27	27	27	27
South Carolina							
South Carolina Elec. & Gas Co.							
Coal	1,500	2,384	2,948	2,687	2,093	2,191	1,549
Oil	139	51	49	701	1,970	1,970	3,272
Gas	1,121	816	734	653	571	489	—
South Carolina Pub. Serv. Auth. (Fiscal Years)							
Coal	670	950	1,024	1,316	1,116	1,126	2,460
Oil	275	0	0	42	215	316	0
Virginia							
Appalachian Power Co.							
Coal	4,499	5,616	—	—	—	—	—
Danville Elec. Dept.							
Coal	42	45	42	40	40	45	—
Gas	55	70	73	71	71	70	—
Virginia Elec. & Pwr. Co.							
Coal	4,916	—	—	—	—	—	—
Virginia Poly. Institute							
Coal	23	18	18	18	18	18	18
Oil	1	1	1	1	2	2	4
Gas	4	10	12	15	18	22	40
West Virginia							
Birch Bottom Power Co. Inc.							
Coal	609	562	—	—	—	—	—
Plant operated jointly for Ohio Power Co. and West Penn Power Co.							
Central Operating Co.							
Coal	2,688	2,719	—	—	—	—	—
Plant operated jointly for Appalachian Pwr. Co. and Ohio Pwr. Co.							

EAST SOUTH CENTRAL

	1970	1971	1972	1973	1974	1975	1980
Alabama							
Alabama Elec. Coop.							
Coal	200	200	200	500	800	800	800
Gas	12	12	12	12	12	12	12
Alabama Power Co.							
Coal	5,087	5,871	7,498	7,853	7,853	9,751	—
Oil	23	24	31	29	30	30	—
Gas	359	360	356	355	350	350	—
Southern Elec. Gen. Co.							
Coal	3,240	3,036	3,080	2,992	2,990	2,990	2,990
Oil	4	4	4	4	4	4	4
Tennessee Valley Author.							
Coal	32,500	35,200	37,000	39,000	39,000	—	—
Oil	0	30	100	150	150	—	—
Gas	750	920	1,165	1,165	1,165	—	—
Kentucky							
Big Rivers Rural Elec. Coop.							
Coal	0	1,420	1,847	2,428	2,772	—	—
Kentucky Power Co.							
Coal	2,155	2,404	—	—	—	—	—
Kentucky Util. Co.							
Coal	1,490	2,240	2,555	2,939	2,817	3,166	5,990
Oil	1	18	28	28	28	28	49
Gas	1	9	9	9	9	9	9
Louisville Gas & Elec. Co.							
Coal	2,200	2,455	2,645	2,850	3,070	3,300	4,850
Gas	375	15	15	15	15	15	—
Owensboro Munic. Util.							
Coal	557	565	575	585	1,200	1,200	2,000
Mississippi							
Mississippi Power Co.							
Coal	600	600	600	1,400	1,400	1,400	2,000
Mississippi Pwr. & Lt. Co.							
Oil	166	200	500	500	500	1,000	2,000
Gas	2,695	2,900	3,500	3,600	3,600	3,000	2,600

WEST SOUTH CENTRAL

	1970	1971	1972	1973	1974	1975	1980
Arkansas							
Jonesboro City Wt. & Lt. Dept.							
Oil	1	1	1	1	1	1	3
Gas	26	29	32	35	52	100	200
Louisiana							
Central Louisiana Elec. Co.							
Gas	1,181	1,418	1,576	1,607	1,756	1,974	3,711
Lafayette Utilities System							
Gas	300	332	367	406	449	497	—
New Orleans Public Service Inc.							
Gas	3,032	2,739	2,511	2,283	2,054	1,826	1,370
Southwestern Elec. Pwr. Co.							
Gas	2,739	2,761	2,725	3,014	3,237	3,546	5,164
Oklahoma							
Oklahoma Gas & Elec. Co.							
Coal	2	2	2	2	2	2	2
Oil	8	8	8	8	8	8	8
Gas	4,091	5,291	5,491	6,191	6,391	6,891	10,291
Public Serv. of Oklahoma							
Gas	3,942	3,971	4,083	4,117	4,612	5,023	8,019
Texas							
Austin Elec. Dept.							
Gas	1,200	1,350	1,500	1,675	2,040	2,260	4,050
Central Pwr. & Lt. Co.							
Gas	3,419	3,825	4,280	4,579	5,296	5,962	9,720
El Paso Elec. Co.							
Coal	257	366	396	364	400	417	425
Oil	0	11	37	127	154	167	283
Gas	1,269	1,187	1,239	1,277	1,383	1,504	2,543
Gulf States Util. Co.							
Gas	7,403	7,930	9,069	9,984	11,070	12,720	23,400
Texas Pwr. & Lt. Co.							
Gas	3,494	3,962	2,436	2,955	3,549	4,397	4,789

MOUNTAIN

	1970	1971	1972	1973	1974	1975	1980
Arizona							
Arizona Elec. Pwr. Coop. Inc.							
Gas	140	182	228	228	274	274	454

APPENDIX I (Concluded)

	1970	1971	1972	1973	1974	1975	1980
Arizona Pub. Serv. Co.							
Coal	5,858	6,678	6,952	7,335	8,012	8,226	9,871
Oil	—	173	155	188	203	354	36
Gas	564	525	593	759	765	746	453
Salt River Project							
Coal	445	1,009	1,111	1,111	1,743	2,722	6,538
Gas	720	840	880	1,000	760	400	160
Colorado							
Colorado Springs Dept. Pub. Util.							
Coal	60	70	80	90	100	125	300
Oil	10	10	10	10	10	10	10
Gas	470	510	550	575	600	625	900
Colorado—Ute. Elec. Assn. Inc.							
Coal	649	644	644	644	644	692	1,232
Fort Collins Lt. & Pwr.							
Coal	4	4	4	4	—	—	—
Oil	1	1	1	1	—	—	—
Gas	13	13	13	13	—	—	—
Lamar Utilities Board							
Gas	42	44	88	90	92	94	100
Public Serv. Co. of Colo.							
Coal	2,320	2,490	2,500	3,000	3,500	4,000	5,800
Oil	32	32	32	32	32	32	30
Gas	1,130	1,280	628	620	620	320	650
Southern Colo. Pwr. Div. Cent. Tel. & Util.							
Coal	200	200	200	200	200	200	200
Oil	2	2	2	2	2	2	2
Gas	200	220	240	240	240	240	240
Western Colorado Power Co.							
Coal	60	54	62	61	62	62	62
Gas	1	1	1	1	1	1	1
Montana							
Montana-Dakota Util.							
Coal	980	850	850	850	850	850	850
Oil	1	1	1	1	1	1	1
Gas	32	16	22	27	27	22	22
Montana Pwr. Co.							
Coal	391	593	631	614	640	902	1,935
Oil[a]	147	79	142	132	187	236	106
[a] Oil and/or Gas.							
Nevada							
Nevada Power Co.							
Coal	540	922	915	1,077	1,340	1,590	2,950
Gas	408	180	127	286	300	300	300
Sierra Pacific Power Co.							
Coal	0	0	0	0	0	0	166
Oil	28	34	60	94	137	130	130
Gas	402	396	426	451	446	501	796
New Mexico							
Farmington Utility							
Oil	1	1	1	1	1	1	1
Gas	68	72	75	80	84	88	113
New Mexico Elec. Serv. Co.							
Gas	260	280	308	336	360	1,660	1,660
Plains Elec. Gen. & Trans. Coop. Inc.							
Gas	30	30	30	30	30	30	30
Raton Pub. Serv. Co.							
Coal	20	21	21	22	22	23	23
Oklahoma							
Blackwell, City of							
Gas	38	38	38	38	38	38	38
Utah							
California-Pacific Utils.							
Coal	8	9	10	—	—	—	—
Provo Dept. Pub. Util.							
Coal	165	165	165	165	165	—	—
Gas	4	—	—	—	—	—	—
Utah Power & Light Co.							
Coal	1,676	2,011	3,522	3,751	3,991	4,255	—
Oil	439	332	248	0	0	0	—
Gas	128	364	4	0	0	0	—
Wyoming							
Pacific Power & Lt. Co.							
Coal	1,800	3,500	6,000	7,700	9,000	10,300	13,600
(Includes Washington Wt. Pwr. Co.-Centralia, Wash.)							

PACIFIC

	1970	1971	1972	1973	1974	1975	Dec.
California							
Los Angeles Dept. Wt. & Pwr.							
Coal	—	432	741	832	1,147	1,667	2,819
Oil	1,354	2,482	3,330	4,342	5,158	5,850	1,012
Gas	4,506	3,647	3,234	2,752	2,421	2,323	4,050
[a] Coal burn in 1980 could include 6,613,000 more tons either nuclear or coal.							
San Diego Gas & Elec. Co.							
Coal	0	0	0	0	0	0	1,994
Oil	545	661	654	1,448	1,562	1,845	452
Gas	2,081	2,189	2,509	1,582	1,764	1,671	560
Southern Calif. Edison Co.							
Coal	0	4,160[a]	4,980[a]	5,095[a]	4,960[a]	4,935[a]	—
Oil	2,865	—	—	—	—	—	—
Oil & Gas	12,686	14,865	16,610	18,395	20,530	23,285	—
[a] Coal burn is at Mohave Station, Nevada. Station owned 56% SCE; 20% L.A. Dept. Wt. & Pwr.; 14% Nev. Pwr.; 10% Salt River Project.							
[b] Combined oil & gas. 1970 percentages: Gas, 81%; Oil, 19%							

APPENDIX II

Analyses and Fusibility of Ash From Various U. S. Coals (82)

County and bed	Sample No.	Percent of moisture-free coal		Analysis of ash, percent										Fusibility of ash		
		Ash	Sulfur	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	Na_2O	K_2O	SO_3	Initial deformation temperature, °F	Softening temperature, °F	Fluid temperature, °F
ALABAMA																
Jefferson:																
Clements, top	1	13.6	1.8	38.4	22.2	35.6	1.1	0.12	1.7	0.8	0.2	2.2	0.6	2,080	2,130	2,300
Clements, bottom	2	6.9	1.6	45.2	23.5	25.9	1.0	.17	1.8	.9	.2	2.6	.6	2,100	2,180	2,480
Clements, middle	3	8.5	1.7	45.4	24.9	22.8	1.2	.08	1.8	1.7	.3	2.5	.6	2,160	2,260	2,360
Mary Lee	4	11.7	.9	53.1	31.1	7.0	1.8	.41	1.8	1.7	.2	4.0	.9	2,910+	-	-
Pratt	5	7.0	1.7	42.7	29.3	19.2	1.0	.46	3.7	.6	.3	1.4	.7	2,520	2,670	2,680
Marion: Black Creek	6	5.2	1.1	45.2	24.9	15.6	.8	.31	3.8	1.9	.3	2.4	3.6	2,310	2,380	2,600
Shelby: Montevallo	7	7.3	.8	35.4	14.8	17.9	.6	.06	12.4	2.4	.2	2.8	7.4	2,080	2,130	2,180
Tuscaloosa:																
Brookwood	8	17.0	1.2	51.0	33.3	7.6	1.3	.28	1.7	1.5	.2	2.8	.6	2,910+	-	-
Clements	9	4.5	1.3	42.3	27.4	20.4	.6	.10	1.9	1.4	.2	3.2	2.1	2,150	2,250	2,390
Millsdale	10	5.3	1.0	48.2	28.4	15.1	1.4	.13	1.8	.8	.3	1.2	2.4	2,600	2,680	2,780
Walker:																
Black Creek	11	5.5	2.8	23.9	18.4	45.0	.8	.13	3.4	.8	.3	.9	4.7	2,020	2,150	2,530
Cobb	12	11.0	2.2	43.7	27.9	21.4	1.3	.12	1.7	1.3	.3	2.5	1.6	2,260	2,400	2,600
Mary Lee	13	14.0	.8	54.0	37.5	5.3	1.2	.57	1.7	1.0	.2	2.2	.9	2,910+	-	-
Johnson: Lower Hartshorne	14	9.0	.7	41.1	27.4	20.0	.9	1.3	.4	4.4	1.1	1.1	10.3	2,170	2,300	2,500
Lower Pratt	15	12.1	2.5	24.6	12.0	14.5	.6	.82	18.9	5.4	.8	1.3	16.0	2,180	2,240	2,300
Fremont:																
Unknown	16	15.9	0.4	33.4	23.4	3.2	1.1	0.01	8.5	0.9	0.4	0.2	6.6	2,370	2,460	2,580
Do	17	8.6	.4	46.6	21.2	7.9	1.0	.00	9.4	1.1	.1	.1	11.8	2,260	2,360	2,480
Do	18	6.4	.7	48.9	15.2	6.8	1.1	.04	11.3	.9	.2	.2	14.9	2,150	2,260	2,460
La Plata:																
Unknown	19	5.2	1.1	47.7	30.4	11.6	1.4	.13	5.3	.6	.4	.2	1.8	2,490	2,560	2,630
Do	20	8.0	.6	60.5	26.1	6.0	1.4	.04	1.8	.4	.2	.3	.3	2,910	2,910+	-
Las Animas:																
Unknown	21	9.2	.6	48.2	28.2	8.7	1.4	2.8	4.8	1.6	.3	.2	2.4	2,560	2,660	2,770
Do	22	19.2	.6	71.8	21.9	3.2	1.6	.08	.4	.4	.2	.3	.2	2,910+	-	-
Mesa:																
Unknown	23	13.2	.9	50.0	33.3	4.1	1.2	.43	5.9	.5	1.8	.6	1.5	2,730	2,890	2,910+
Do	24	12.3	.6	47.7	34.2	3.3	1.4	.20	6.2	2.4	1.0	.2	1.7	2,720	2,740	2,840
Moffat: Unknown	25	5.0	.4	54.8	20.7	6.0	1.7	.38	12.8	2.0	3.0	.3	15.1	2,330	2,430	2,520
Montrose: Unknown	26	11.9	.5	56.6	34.2	5.1	1.6	.02	1.8	.6	.2	.8	.6	2,910+	-	-
Routt: Hale	27	5.1	.6	46.6	30.6	-	-	-	4.6	1.1	.2	.6	4.6	2,740	2,910+	-
Fulton: No.	28	10.8	3.3	31.1	20.1	34.1	0.7	0.16	6.5	0.8	0.5	2.0	2.8	1,940	2,040	2,230
Henry: No. 6	29	7.5	3.2	41.4	20.3	23.3	.5	.16	6.8	1.9	.5	2.1	2.4	1,910	2,020	2,110
Jackson: No. 6	30	8.3	2.4	43.7	22.3	19.5	1.2	.06	1.7	.8	.4	2.2	1.0	2,130	2,210	2,470
Kankakee: Nos. 2 and 5	31	6.5	2.1	36.0	20.5	35.4	1.0	.11	1.8	.6	.6	1.8	1.2	1,940	2,010	2,310
Peoria: No. 6	32	8.3	3.0	42.7	23.2	23.9	.7	.11	3.4	.9	.3	2.3	.8	2,000	2,130	2,220
Randolph: No. 6	33	17.1	4.5	46.6	19.3	26.4	.8	.24	1.7	.9	.2	1.7	2.4	1,980	2,060	2,360
Saline: Davis	34	12.7	4.3	42.5	18.3	34.6	.9	.20	1.7	.4	.3	1.8	1.0	2,040	2,130	2,180
Schuyler: No. 5	35	10.7	3.6	48.0	14.7	18.7	.6	.44	10.4	.6	.2	1.8	2.1	1,940	2,000	2,230
Stark: No. 6	36	8.9	3.1	42.1	20.1	22.4	1.1	.11	6.6	1.1	.5	1.9	2.0	2,100	2,150	2,360
Vermilion: No. 7	37	9.1	3.0	43.8	20.2	20.0	1.0	.03	6.1	1.3	.6	2.3	2.2	2,020	2,090	2,320
Williamson: Davis	38	10.2	3.0	39.4	17.7	27.0	1.0	.12	3.4	.9	.3	1.6	1.1	2,070	2,100	2,410
Clay: No. III	39	7.2	4.0	43.4	20.3	31.6	0.8	0.22	6.1	0.6	0.3	1.3	1.8	1,940	2,040	2,140
Greene:																
No. IV	40	7.6	1.4	46.7	31.6	12.8	1.2	.39	1.8	1.2	.3	3.3	.4	2,620	2,700	2,790
No. V	41	8.7	2.8	51.7	29.3	13.9	1.2	.03	1.8	1.0	.3	2.4	.6	2,470	2,570	2,680
Knox:																
No. V	42	9.2	3.4	47.6	23.6	15.5	1.1	.10	3.2	.8	.4	2.6	1.0	2,160	2,290	2,560
No. VI	43	10.2	2.7	51.6	21.8	17.0	1.0	.09	1.7	1.1	.6	3.7	.4	2,260	2,440	2,730
Owen: Upper Block	44	7.6	2.6	51.9	23.4	17.5	1.2	.27	1.6	.7	.2	1.7	.4	2,260	2,470	2,570
Pike: No. V	45	9.1	3.1	42.9	22.3	29.3	1.1	.18	1.9	.6	.2	2.0	.6	2,010	2,110	2,430
Sullivan:																
No. VI	46	9.1	2.5	47.9	22.5	21.4	1.2	.10	1.7	.9	1.1	2.6	.9	2,050	2,140	2,290
No. VII	47	9.7	.7	60.9	23.4	7.0	1.3	.02	1.8	1.5	.3	3.1	.2	2,520	2,680	2,800
Vigo:																
No. V	48	14.0	4.5	49.1	18.9	23.0	.9	.11	4.3	.7	1.0	2.0	2.2	1,930	2,020	2,310
No. VI	49	10.0	4.4	30.7	16.1	40.7	.8	.07	7.4	.5	.2	1.3	1.4	1,900	2,000	2,430
No. VII	50	8.1	1.1	55.2	26.5	9.5	1.2	.04	1.7	1.2	.3	2.7	.4	2,540	2,660	2,720
Warrick: No. V	51	12.4	4.2	35.4	18.6	37.7	1.0	.06	4.4	.6	.4	2.4	1.1	2,050	2,110	2,730
ARKANSAS																
Appanoose: Musti	52	10.8	5.0	29.0	12.1	32.0	0.9	0.02	15.0	1.6	0.8	1.2	3.7	1,940	1,990	2,070
Nation: Unknown	53	16.0	5.3	33.6	11.7	34.1	.9	.16	4.3	.9	.2	1.2	2.4	2,010	2,070	2,260
KANSAS																
Cherokee: Fleming and Mineral	54	9.2	3.3	40.5	14.2	25.0	0.6	0.05	11.7	0.8	0.4	1.6	4.0	1,940	2,000	2,040
Crawford: Weir-Pittsburg	55	11.7	4.7	35.9	18.1	40.5	.7	.27	1.8	.3	.2	.4	1.4	2,000	2,050	2,360
KENTUCKY																
Bell:																
Hance	56	9.4	1.2	50.5	30.0	11.4	1.2	0.61	1.8	1.1	0.4	3.0	0.8	2,590	2,700	2,790
Hazard No. 4	57	5.6	.9	46.9	26.4	12.0	1.2	.24	2.7	2.0	.2	2.0	4.5	2,680	2,570	2,730
Mason	58	2.2	1.1	31.6	29.8	20.0	1.3	.10	5.7	2.1	.3	1.5	6.6	2,320	2,370	2,650

APPENDIX B (Continued)

County and bed	Sample No.	Percent of moisture-free coal		Analysis of ash, percent										Fusibility of ash		
		Ash	Sulfur	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	Na_2O	K_2O	SO_3	Initial deformation temperature, °F	Softening temperature, °F	Fluid temperature, °F
KENTUCKY--Continued																
Hopkins:																
No. 9	59	7.9	3.3	43.7	22.1	29.0	1.0	0.23	0.9	0.4	0.2	2.3	0.8	2,050	2,140	2,430
No. 12	60	15.6	3.1	57.9	18.8	11.3	1.0	.13	5.1	1.2	.7	2.8	1.7	2,100	2,210	2,540
Knott:																
Hazard No. 4	61	9.6	.8	56.3	32.6	4.5	1.0	.05	1.7	1.5	.5	1.6	.9	2,910+	-	-
Hazard No. 7	62	4.4	.7	56.7	30.7	4.8	1.6	.05	1.7	.9	.3	.9	2.0	2,910+	-	-
Do	63	9.1	.6	57.8	29.8	4.1	1.7	.13	1.7	1.0	.2	2.0	1.1	2,910+	-	-
Letcher: Hazard No. 4	64	4.5	.8	47.9	32.4	9.8	1.4	.10	1.6	.8	1.8	1.4	2.1	2,740	2,800	2,900
Martin: Pond Creek	65	8.4	1.1	53.1	29.1	9.1	1.8	.08	1.8	.6	.4	2.2	1.8	2,540	2,680	2,730
Muhlenburg:																
No. 11	66	6.8	3.3	39.3	20.6	31.3	1.1	.17	2.5	.5	.3	2.3	1.2	2,010	2,210	2,360
Do	67	6.4	3.2	41.8	23.9	27.8	1.1	.07	1.8	.6	.2	2.3	.9	2,050	2,150	2,360
Do	68	7.7	3.2	43.2	26.0	24.3	1.1	.27	1.8	.8	.2	2.0	1.4	2,020	2,110	2,450
No. 12	69	12.2	2.7	53.6	23.0	15.9	1.1	.11	1.8	.9	.2	3.1	.9	2,210	2,400	2,610
Do	70	11.5	2.6	49.9	24.0	16.7	1.0	.08	2.6	.9	.2	2.7	1.1	2,110	2,230	2,500
Do	71	13.6	3.1	52.2	22.7	16.3	1.1	.13	2.3	1.3	.2	3.1	1.6	2,070	2,140	2,420
Do	72	12.7	3.2	53.0	23.4	16.0	1.2	.16	2.4	1.4	.2	3.1	.5	2,320	2,500	2,570
Do	73	11.5	2.9	47.2	26.4	21.0	1.1	.48	1.5	1.0	.2	2.5	.3	2,200	2,500	2,680
No. 13	74	9.3	2.2	46.2	29.4	18.4	1.1	.10	1.8	.8	.2	2.4	.4	2,240	2,700	2,780
Ohio: No. 9	75	8.3	3.5	49.3	19.4	27.4	1.0	.03	1.8	.7	.2	1.9	.2	2,100	2,160	2,390
Perry: Hazard No. 9	76	9.5	2.7	46.7	28.8	19.1	1.2	.14	1.7	.3	.2	1.0	1.0	2,680	2,730	2,780
Pike:																
Elkhorn No. 1	77	8.3	.8	52.0	34.5	8.4	1.8	.11	1.9	.6	.3	3.3	.6	2,910+	-	-
Elkhorn No. 2	78	6.9	.9	52.9	27.8	9.7	1.3	.10	1.7	1.6	.3	4.1	1.3	2,730	2,780	2,890
Elkhorn No. 3	79	4.6	1.2	48.7	26.3	12.9	2.3	.10	1.8	1.0	1.0	2.1	2.5	2,470	2,600	2,750
Williamson	80	8.0	2.5	36.9	26.3	25.6	1.3	.09	3.4	.4	.3	1.7	2.9	2,120	2,160	2,270
Winifrede	81	5.2	.7	55.5	24.9	7.1	2.2	.04	2.9	1.1	.4	1.1	4.0	2,960	2,740	2,860
Union: No. 9	82	9.5	3.2	50.3	20.6	18.9	1.0	.14	2.0	.8	.7	3.2	2.0	1,970	2,130	2,440
Webster: No. 14	83	9.0	2.9	42.4	22.4	30.4	.8	.13	1.4	.4	.2	1.8	.9	2,000	2,110	2,410
MARYLAND																
Allegany: Pittsburgh and Tyson	84	10.4	0.9	57.1	31.6	4.7	1.6	0.37	2.0	0.5	0.9	2.6	0.4	2,890	2,910+	-
Garrett: Upper and Lower Kittanning	85	8.6	1.7	46.2	28.1	16.4	1.7	.03	1.7	.8	.3	2.5	1.3	2,570	2,670	2,740
MISSOURI																
Henry: Tebo	86	11.8	4.7	45.4	15.6	26.7	0.7	0.14	6.2	0.6	0.1	1.7	3.0	2,000	2,050	2,360
Macon: Bevier	87	10.1	5.2	37.9	16.3	41.0	.6	.02	1.7	.4	.1	1.3	1.1	1,960	2,020	2,230
St. Clair: Tebo	88	17.8	4.3	43.6	14.5	27.6	.7	.14	7.0	.8	.2	3.0	3.5	1,960	2,020	2,320
Vernon: Mineral	89	12.2	4.2	41.9	16.6	30.7	.8	.11	4.7	.8	.2	2.3	2.2	1,950	2,020	2,270
MONTANA																
Big Horn: Unknown	90	4.2	0.4	22.1	15.3	6.4	1.2	0.11	18.9	6.6	1.0	0.4	26.2	2,260	2,380	2,470
Dawson:																
Unknown	91	16.9	.7	30.0	25.3	2.9	.6	.76	11.7	4.9	8.1	.4	12.6	-	-	-
Do	92	19.3	.9	30.7	21.3	3.4	.6	.69	11.7	3.8	7.4	.9	16.7	-	-	-
Garfield: Unknown	93	16.8	.6	43.2	23.7	4.7	.6	.05	10.0	2.8	2.0	1.8	9.0	-	-	-
Park:																
Unknown	94	13.6	.5	53.6	31.9	5.8	1.0	.02	1.8	1.4	.8	.3	2.4	-	-	-
Do	95	7.2	.5	46.2	19.3	8.9	.9	.76	8.7	2.9	.1	.6	11.8	-	-	-
Richland: Unknown	96	10.0	.5	21.9	13.8	5.9	.7	.46	31.4	10.4	.3	.3	12.6	2,550	2,640	2,560
NEW MEXICO																
Colfax: Yankee	97	12.6	0.6	57.4	30.0	6.7	1.2	0.07	1.7	2.0	0.1	1.0	0.5	2,860	2,910+	-
McKinley: Aztec	98	16.3	1.1	61.9	22.9	7.8	.8	.01	3.2	1.5	.7	1.1	2.1	2,420	2,470	2,570
Rio Arriba: Unknown	99	10.9	3.2	47.2	20.4	27.3	1.0	.06	4.3	.8	.3	.2	.6	2,170	2,230	2,370
Sandoval: Fasenan	100	5.3	1.5	28.9	14.3	22.1	.9	.12	11.2	4.2	.5	.2	17.3	2,020	2,040	2,210
San Juan: Unknown	101	2.9	.7	42.8	22.3	15.2	1.3	.08	3.9	2.7	2.2	.1	6.0	2,120	2,160	2,300
Socorro: Carthage	102	14.6	.8	36.7	21.0	7.6	1.1	.02	14.5	.8	.2	.9	1.6	2,300	2,360	2,520
NORTH DAKOTA																
Bowman: Unknown	103	10.9	1.5	40.4	10.6	4.1	0.9	0.04	14.7	5.4	2.3	0.2	20.3	2,110	2,190	2,240
Burke: Unknown	104	12.6	1.0	31.2	16.6	6.0	.9	.04	14.5	3.3	7.3	.2	19.2	2,020	2,060	2,110
Mercer:																
Zap	105	12.1	1.1	23.8	10.5	10.1	.6	.27	16.6	5.1	8.2	.6	23.5	1,900	1,940	2,060
Unknown	106	9.3	1.0	15.4	8.0	9.2	.6	.42	21.3	6.7	7.1	.3	27.4	2,470	2,520	2,570
Ward:																
Coteau	107	7.5	.5	45.0	13.0	6.1	.7	.37	16.0	10.8	.9	.3	16.6	2,470	2,470	2,520
Do	108	12.4	.8	31.9	13.5	5.6	.7	.13	21.4	7.0	.5	.6	16.8	2,130	2,190	2,240
OHIO																
Belmont:																
Pittsburgh (No. 8)	109	10.8	4.3	42.4	19.6	27.5	0.9	0.15	4.6	1.2	0.2	1.6	2.0	2,020	2,080	2,290
Do	110	12.9	4.3	45.3	21.2	23.3	1.0	.11	1.9	.6	.2	1.6	.7	2,080	2,230	2,420
Do	111	9.0	3.4	44.2	21.8	26.4	1.0	.13	3.8	.9	.4	1.7	1.8	-	-	-
Sewickley (No. 9)	112	11.3	3.7	49.7	22.7	21.2	1.0	.05	1.6	1.7	.3	2.0	1.5	2,100	2,210	2,390
Do	113	11.6	2.4	54.6	24.0	17.1	1.1	.04	1.8	.6	.3	1.9	.2	2,340	2,480	2,530
Do	114	12.3	3.3	52.7	21.9	21.4	1.1	.07	1.8	.6	.2	1.7	1.1	2,130	2,210	2,410
Do	115	12.4	2.6	53.9	24.4	16.4	.9	.11	1.6	.7	.3	2.3	.5	2,530	2,620	2,740
Carroll:																
Lower Freeport (No. 7)	116	12.0	2.4	47.2	26.6	21.4	1.3	.27	1.9	1.0	.2	1.2	.7	2,180	2,320	2,640
No. 7A	117	10.2	2.9	40.3	23.8	32.7	.9	.38	1.8	.6	.2	1.0	.9	2,060	2,130	2,470

APPENDIX II (Continued)

County and bed	Sample No.	Percent of moisture-free coal		Analysis of ash, percent										Fusibility of ash		
		Ash	Sulfur	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	Na_2O	K_2O	SO_3	Initial deformation temperature, °F	Softening temperature, °F	Fluid temperature, °F
OHIO--Continued																
Columbiana: Middle Kittanning (No. 6)	118	9.4	3.9	30.2	21.2	45.2	0.8	0.19	1.8	0.7	0.2	1.0	0.8	2,080	2,180	2,470
Coshocton: Middle Kittanning (No. 6)	119	5.9	3.2	31.6	21.3	40.7	.9	.08	1.8	.6	.2	1.2	1.8	2,110	2,220	2,460
Gallia: Lower Kittanning (No. 5)	120	17.1	4.9	34.6	28.9	33.2	.8	.21	1.7	.2	.1	1.0	.7	2,180	2,360	2,580
Guernsey: Anderson	121	11.7	3.1	48.9	22.4	19.0	1.4	.55	3.1	1.1	.3	1.6	2.0	2,060	2,190	2,310
Harrison:																
Pittsburgh (No. 8)	122	12.6	4.6	40.6	18.8	34.8	.9	.16	2.0	.5	.2	1.4	.7	1,970	2,080	2,360
Sewickley (No. 9)	123	13.7	2.6	53.1	26.4	18.7	1.1	.17	.4	.8	.3	2.0	.3	2,520	2,570	2,780
Jefferson:																
Harlem	124	11.2	2.2	53.1	20.9	19.2	.9	.24	1.7	1.0	.3	2.7	.8	2,150	2,310	2,500
Lower Freeport (No. 6A)	125	10.4	5.1	29.4	21.3	44.5	.8	.04	1.8	.4	.4	1.5	1.1	2,260	2,420	2,570
Middle Kittanning (No. 6)	126	8.6	2.4	41.3	26.6	25.5	1.4	.91	1.8	.3	.2	1.1	.8	2,280	2,470	2,570
Pittsburgh (No. 8)	127	11.5	3.2	49.4	23.3	23.7	1.1	.24	1.9	.7	.4	1.9	.8	2,100	2,260	2,560
Do	128	10.4	2.6	50.4	23.2	21.9	1.0	.18	1.9	.5	.1	1.0	.4	2,140	2,310	2,670
Do	129	9.7	3.7	43.9	21.5	29.5	1.1	.17	1.9	.7	.2	1.5	1.2	1,980	2,130	2,360
Do	130	12.6	3.3	50.2	25.1	21.0	1.0	.09	1.9	.5	.4	1.9	.5	2,440	2,620	2,820
Do	131	11.5	3.1	48.1	21.6	24.5	1.1	.18	1.9	.6	.2	1.8	1.1	2,070	2,150	2,440
Do	132	9.7	2.4	48.2	24.2	22.0	1.1	.24	1.8	.7	.2	1.6	1.0	2,060	2,270	2,580
Do	133	15.0	4.0	42.4	19.9	24.3	1.0	.27	4.1	.9	.2	1.6	3.6	2,240	2,300	2,510
Do	134	11.9	3.4	48.0	22.5	26.0	.9	.15	1.8	.9	.2	1.1	.8	2,120	2,230	2,480
Lawrence: Lower Kittanning (No. 5)	135	4.6	1.7	33.1	29.6	30.6	.6	.25	1.8	.3	.1	.4	2.6	2,130	2,180	2,310
Mahoning: Brookville (No. 4)	136	14.7	6.3	34.3	18.1	39.7	2.2	.09	1.8	.2	.2	1.2	1.6	2,020	2,050	2,270
Meigs: Redstone (No. 8A)	137	8.7	1.2	56.1	30.2	8.6	1.4	.24	1.8	.6	.2	1.6	.6	2,890	2,910+	-
Morgan: Sewickley (No. 9)	138	16.7	4.5	46.0	20.3	24.6	.8	.30	1.8	1.5	.3	1.9	1.8	1,950	2,080	2,370
Noble: Sewickley (No. 9)	139	17.2	6.9	36.7	19.9	37.8	.8	.23	1.8	.6	.2	1.4	.7	2,000	2,060	2,420
Perry: Lower Kittanning (No. 5)	140	12.9	4.3	31.8	23.9	39.5	.6	.52	1.8	.3	.1	.9	.4	1,970	2,100	2,470
Stark: Middle Kittanning (No. 6)	141	14.9	5.1	39.9	22.0	34.8	.8	.11	1.9	.7	.2	1.8	1.1	2,030	2,150	2,470
Tuscarawas:																
Lower Kittanning (No. 5)	142	10.8	3.6	43.6	22.3	28.5	1.2	.19	1.8	.7	.2	1.0	1.9	2,050	2,130	2,470
Middle Kittanning (No. 6)	143	8.0	4.1	32.2	20.7	43.2	.9	.06	1.9	.7	.3	.5	2.1	2,020	2,130	2,330
Washington: Sewickley (No. 9)	144	12.2	5.7	40.0	20.2	35.5	.8	.06	1.8	.4	.3	1.5	.7	1,950	2,050	2,360
PENNSYLVANIA																
Allegheny: Pittsburgh	145	7.9	2.0	49.2	24.8	20.3	1.0	0.14	1.8	0.5	0.2	3.6	1.3	2,410	2,520	2,620
Armstrong:																
Upper Freeport	146	10.0	1.7	50.5	27.4	16.8	1.1	.32	1.8	.9	.2	2.5	1.0	2,570	2,620	2,780
Do	147	10.5	2.1	47.4	28.4	19.9	.8	.52	1.8	.7	.2	2.6	1.0	2,300	2,570	2,690
Beaver:																
Lower Kittanning	148	6.7	1.4	42.5	32.7	15.4	.9	1.2	2.0	.3	.2	1.2	1.6	2,620	2,780	2,910+
Upper Freeport	149	7.8	2.9	35.9	22.2	38.5	.9	.38	1.8	.3	.2	1.0	1.2	2,020	2,110	2,440
Bedford: Lower Kittanning	150	10.2	.7	57.7	32.1	5.1	1.7	.18	1.7	.9	.2	2.6	.2	2,910+	-	-
Butler:																
Middle Kittanning	151	13.4	6.3	26.9	18.2	52.5	1.1	.60	1.2	.4	.2	1.0	.8	2,000	2,060	2,230
Upper Freeport	152	12.4	2.8	44.9	24.7	23.1	1.8	.54	2.2	.6	.3	3.4	.8	2,180	2,260	2,520
Cambria:																
Lower Kittanning	153	8.7	2.3	37.4	26.3	33.3	1.1	.11	1.8	.4	.1	1.0	1.6	2,090	2,290	2,490
Upper Freeport	154	12.0	2.0	46.0	24.8	22.9	.7	.13	1.7	.6	.2	2.2	1.5	2,130	2,180	2,280
Do	155	13.2	2.0	50.9	24.9	17.2	1.1	.30	1.7	1.0	.2	2.8	1.2	2,360	2,550	2,660
Clarion:																
Clarion	156	9.9	4.5	32.7	20.9	43.3	1.0	.28	1.4	.2	.1	.8	1.4	2,110	2,130	2,420
Upper Freeport and Lower Kittanning	157	9.4	1.0	56.5	28.3	9.5	.9	.29	1.7	.3	.2	2.6	1.0	2,730	2,810	2,910+
Clearfield:																
Lower Freeport	158	9.2	3.5	36.4	21.2	38.2	.7	.20	1.7	.3	.2	1.0	1.1	2,020	2,080	2,210
Lower Kittanning	159	10.9	3.6	33.9	23.7	38.5	.9	.06	1.7	.3	.2	1.3	1.1	2,100	2,240	2,570
Upper Freeport	160	11.5	.9	53.6	28.1	11.1	1.0	.46	1.5	.7	.2	3.2	.7	2,730	2,800	2,910
Elk: Clarion	161	9.7	2.3	42.1	24.3	24.6	1.3	.12	1.8	.3	.2	1.0	2.0	2,120	2,260	2,560
Fayette: Pittsburgh	162	9.2	2.0	49.8	25.2	16.0	1.1	.24	3.3	.7	.4	1.7	1.9	2,130	2,180	2,470
Indiana:																
Lower Freeport	163	11.3	2.6	43.1	26.5	25.5	1.0	.49	1.8	.4	.2	2.1	.9	2,100	2,180	2,290
Do	164	8.7	1.3	49.4	31.6	11.8	1.2	.16	1.6	.8	.2	2.0	1.2	2,870	2,910	2,910+
Lower Kittanning	165	6.9	1.3	49.3	30.7	11.9	.9	.18	1.7	.5	.1	1.8	1.8	2,360	2,420	2,470
Upper Freeport	166	8.8	2.0	43.4	31.2	21.6	1.2	.29	2.1	.4	.1	1.2	1.1	2,500	2,560	2,670
Do	167	8.2	1.7	42.0	29.4	20.7	.9	1.1	1.9	.3	.3	1.9	1.9	2,220	2,500	2,620
Jefferson: Lower Kittanning	168	7.6	1.1	47.5	30.8	9.3	1.6	2.9	3.6	.4	.1	1.1	1.5	2,680	2,730	2,780
Lawrence:																
Brookville	169	10.3	2.4	53.4	25.6	24.2	1.6	1.2	1.9	.3	.2	1.1	.2	2,080	2,260	2,570
Lower Kittanning	170	11.2	3.1	33.7	18.5	42.7	1.1	.84	1.8	.3	.2	1.1	.3	1,950	2,020	2,330
Mercer:																
Brookville	171	5.7	1.2	34.0	28.7	25.3	1.4	.60	5.3	.7	.4	1.2	2.7	2,250	2,340	2,540
Do	172	8.4	1.1	34.2	24.0	23.6	.7	.33	4.9	.7	.5	1.4	3.6	2,250	2,310	2,470
Somerset: Lower Kittanning	173	8.0	2.3	35.1	28.7	31.4	1.0	.11	1.6	.3	.2	.6	2.1	2,180	2,420	2,550
Washington: Pittsburgh	174	9.8	1.1	47.6	25.8	9.6	1.1	.23	9.1	1.4	.5	1.5	3.0	-	-	-
Westmoreland: Pittsburgh	175	8.1	1.0	54.0	29.3	7.8	1.3	.14	2.7	.9	.4	1.9	1.4	2,680	2,730	2,860

APPENDIX II (Continued)

County and bed	Sample No.	Percent of moisture-free coal		Analysis of ash, percent										Fusibility of ash		
		Ash	Sulfur	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	Na_2O	K_2O	SO_3	Initial deformation temperature, °F	Softening temperature, °F	Fluid temperature, °F
TENNESSEE																
Anderson: Dean	176	16.5	3.8	45.4	25.[illegible]	14.9	1.0	0.36	1.7	1.6	0.5	2.9	1.6	2,170	2,280	2,460
Campbell: Dean	177	13.9	3.5	44.3	23.7	19.5	1.7	.73	1.8	.7	.2	2.0	2.1	2,090	2,180	2,470
Claiborne:																
Jellico	178	4.8	.9	49.4	32.7	9.5	1.7	.57	1.8	.7	.5	2.0	1.5	2,910+	-	-
Do	179	5.2	.8	46.3	29.7	11.6	1.4	.75	1.8	1.5	.5	2.4	2.1	2,730	2,780	2,840
Mason	180	10.7	1.8	46.4	27.4	17.2	.9	.13	1.7	1.5	.3	4.7	.6	2,210	2,410	2,680
Grundy:																
Sewanee	181	9.6	.9	56.5	25.8	7.3	1.0	1.1	1.7	1.5	.2	3.1	1.1	2,630	2,730	2,910+
Upper Sewanee	182	9.7	.9	54.3	26.7	7.1	1.2	1.6	2.1	1.5	.2	3.0	1.1	2,610	2,670	2,730
Marion: Sewanee	183	10.0	.6	55.0	25.9	6.1	1.0	1.6	2.9	1.5	.2	2.7	1.8	2,690	2,780	2,870
Morgan: Glen Mary	184	6.1	2.0	44.3	28.8	20.2	1.3	.41	1.8	1.2	.2	2.9	1.2	2,130	2,230	2,420
Scott:																
Glen Mary	185	9.6	3.9	33.6	18.6	41.6	1.0	.14	2.3	.9	.4	1.0	3.0	2,020	2,080	2,140
Stearns No. 2	186	17.2	4.1	43.8	25.0	23.3	1.1	.29	1.7	1.1	.3	2.1	1.8	2,020	2,080	2,290
Sequatchie: Sewanee	187	11.8	1.0	53.1	26.3	7.6	1.0	1.8	1.7	1.3	.2	3.3	1.0	2,740	2,790	2,900
UTAH																
Carbon:																
Castlegate D	188	8.1	0.4	50.5	10.3	4.9	0.9	0.62	17.2	7.6	0.4	0.4	6.6	2,110	2,260	2,390
Do	189	9.6	.5	48.7	15.1	4.9	1.0	.62	13.3	6.0	.5	.6	8.3	2,190	2,260	2,360
Rock Canyon	190	8.0	2.2	51.1	19.8	19.3	.8	1.4	3.5	.3	.5	.7	1.8	2,130	2,230	2,490
Unknown	191	5.7	.6	55.7	15.1	6.6	.9	1.2	12.0	.6	.4	.3	4.3	2,180	2,310	2,440
Do	192	7.0	.4	54.3	12.3	5.7	.9	.23	11.0	4.1	.9	1.4	8.6	2,220	2,260	2,570
Emery:																
Ferron "A"	193	6.3	.5	46.7	19.2	8.0	1.3	.90	10.9	4.5	1.5	.2	6.8	2,140	2,220	2,380
Ferron J	194	8.2	1.4	39.4	15.5	9.6	1.2	.20	17.0	4.5	3.1	.1	8.1	2,070	2,120	2,210
Unknown	195	9.6	.7	58.1	20.3	3.7	1.2	.55	5.7	.8	4.2	1.1	2.8	2,360	2,420	2,570
Do	196	7.2	.5	63.2	13.8	4.3	.8	.10	5.9	1.0	4.3	1.1	4.9	2,180	2,310	2,530
Sevier: Hiawatha	197	6.9	.4	46.4	9.1	7.0	.6	.03	21.9	3.6	1.0	.1	7.5	2,080	2,110	2,150
VIRGINIA																
Buchanan:																
Hagy	198	6.3	1.0	54.8	28.6	11.4	1.5	0.11	1.0	0.8	1.1	1.9	0.8	2,780	2,880	2,910+
Do	199	5.5	1.6	43.1	29.5	21.9	1.4	.25	1.9	.4	1.1	.9	1.3	2,150	2,470	2,590
Kennedy	200	7.7	1.1	43.6	31.6	15.6	1.1	.14	1.9	1.8	.5	4.6	1.3	2,150	2,430	2,590
Raven	201	6.0	1.2	45.1	26.7	19.1	.6	.11	1.8	1.9	.5	2.8	.9	2,250	2,470	2,660
Splash Dam	202	5.7	.8	49.4	32.8	8.7	1.8	.56	2.2	.7	1.4	1.5	1.1	2,390	2,560	2,910+
Do	203	5.3	.7	49.9	36.6	5.9	1.6	.35	2.0	.5	1.6	1.0	1.1	2,910+	-	-
Do	204	6.8	.7	54.2	28.1	7.2	1.5	.20	1.7	.9	1.2	2.2	1.0	2,780	2,890	2,910+
Do	205	6.9	.8	54.0	29.4	8.6	1.3	.30	[illegible]	.8	1.1	2.2	1.0	2,730	2,780	2,890
Do	206	6.3	1.0	51.8	26.5	13.2	1.2	.19	1.8	1.6	.9	2.6	1.1	2,520	2,620	2,730
Do	207	5.5	.9	51.7	29.2	11.6	1.2	.08	1.8	1.0	1.0	2.3	1.1	2,660	2,800	2,910+
Dickenson:																
Hagy	208	8.8	1.8	48.1	27.9	19.6	1.9	.10	1.8	.9	.5	2.3	.7	2,420	2,520	2,600
Kennedy	209	2.7	.7	34.8	26.8	28.9	1.0	.17	2.7	1.5	.2	1.2	3.6	2,080	2,190	2,470
Lower Banner	210	6.3	.8	37.0	22.4	11.2	1.4	.14	14.0	4.4	1.3	.3	7.0	2,150	2,290	2,490
Do	211	12.1	1.1	46.5	26.2	10.1	1.1	.36	4.6	2.0	.9	3.6	2.1	2,300	2,360	2,600
Upper Banner	212	6.6	.6	42.3	27.3	11.3	1.1	.07	5.3	3.0	1.8	3.4	5.6	2,260	2,310	2,470
Montgomery: Brushy Mountain	213	31.7	.7	64.0	25.7	4.5	2.1	.07	1.8	.5	.2	1.0	1.0	2,[illegible]90	2,910	2,910+
Russell:																
Jawbone	214	14.0	.6	48.1	23.4	6.5	1.4	.28	10.5	2.6	.7	1.1	2.8	2,330	2,390	2,470
Kennedy	215	6.2	1.3	26.5	19.1	18.6	.8	.04	17.6	2.5	.2	2.2	11.2	2,[illegible]10	2,110	2,210
Lower Banner	216	9.9	.8	47.9	26.7	8.7	1.5	.28	6.6	2.4	.9	2.3	4.4	2,210	2,260	2,430
Tiller	217	6.2	.6	33.7	24.5	9.8	1.3	.33	22.8	1.7	.3	1.9	4.1	2,090	2,210	2,360
Wise:																
Blair	218	5.7	.6	54.5	31.7	8.5	1.6	.32	1.2	1.5	1.1	2.3	1.6	2,6[illegible]0	2,[illegible]40	2,[illegible]0
Clintwood	219	6.2	2.2	32.0	27.4	35.0	1.3	.70	1.9	.6	1.0	.8	2.4	2,0[illegible]0	2,160	2,[illegible]0
Dorchester	220	8.3	1.6	47.3	27.4	17.2	1.7	.36	1.8	1.6	.3	3.0	2.0	2,[illegible]10	2,[illegible]40	2,[illegible]0
Imboden	221	8.3	2.2	46.4	25.5	24.1	1.2	.47	1.2	.9	.4	2.3	.6	2,[illegible]40	2,[illegible]50	2,[illegible]0
Lyons	222	5.5	2.1	37.3	27.4	26.5	1.1	.04	1.8	1.1	1.0	2.9	2.4	2,130	2,240	2,[illegible]0
Taggart	223	1.8	.7	40.1	30.4	14.7	1.2	.13	2.7	1.0	1.[illegible]	[illegible]	3.6	2,210	2,[illegible]40	2,[illegible]0
WASHINGTON																
King:																
Black Knight	224	9.5	0.5	38.8	29.7	5.3	1.2	1.7	7.6	2.6	0.2	0.6	10.5	2,530	2,540	2,[illegible]0
Do	225	22.4	.5	54.1	31.6	2.8	1.6	.16	2.6	1.7	.2	1.0	3.2	2,910+	-	-
Pierce:																
No. 3	226	11.2	.5	45.8	31.7	9.2	2.9	1.6	1.8	1.7	.7	.8	2.7	2,730	2,800	2,870
No. 7	227	6.1	.4	37.2	36.2	6.0	4.7	2.5	3.3	.9	1.5	1.1	3.2	2,[illegible]40	2,[illegible]5[illegible]	-
No. 8	228	14.2	.5	51.2	32.8	5.9	1.6	1.5	1.3	1.2	1.0	1.6	1.2	2,460	2,810	2,910+
No. 11	229	13.0	.5	44.0	37.0	4.1	1.9	2.6	1.7	1.1	.3	1.7	1.0	2,[illegible]0	2,910+	-
WEST VIRGINIA																
Barbour:																
Lower Kittanning	230	10.6	2.9	37.8	27.3	31.1	1.4	0.11	1.1	0.6	0.2	1.1	1.2	2,150	2,270	2,[illegible]0
Do	231	12.[illegible]	.9	52.5	35.6	6.1	1.7	.46	1.8	.6	.2	1.9	.9	2,[illegible]0+	-	-
Pittsburgh	232	9.0	4.5	31.0	20.8	35.2	.9	.10	6.9	1.3	.6	.6	3.9	2,060	2,130	2,260
Do	233	9.1	3.4	38.1	22.2	26.7	1.1	.13	3.0	.7	.6	1.0	2.8	2,130	2,[illegible]0	2,[illegible]0
Do	234	9.8	4.5	32.9	22.3	39.7	.8	.09	1.8	.5	.8	.8	2.0	1,990	2,250	2,[illegible]0
Redstone	235	7.1	1.5	47.2	30.1	15.7	1.2	1.7	2.1	.7	.7	1.6	1.5	2,450	2,530	2,[illegible]0
Do	236	8.5	1.9	44.6	26.4	19.3	1.2	.32	4.4	.8	.2	1.2	2.5	2,[illegible]0	2,150	2,[illegible]0
Upper Freeport	237	16.2	3.0	35.4	17.9	43.7	.8	1.1	1.0	.8	.1	1.1	1.1	2,000	2,070	2,[illegible]0
Upper Kittanning	238	14.2	2.4	47.0	30.0	17.0	1.3	.32	1.8	.8	.2	2.1	1.0	2,6[illegible]0	2,730	2,[illegible]0
Do	239	13.3	1.9	48.4	32.3	14.7	1.0	.33	1.8	.8	.2	2.6	.7	2,740	2,8[illegible]0	2,[illegible]0

APPENDIX II (Continued)

County and bed	Sample No.	Percent of moisture-free coal		Analysis of ash, percent										Fusibility of ash		
		Ash	Sulfur	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	Na_2O	K_2O	SO_3	Initial deformation temperature, °F	Softening temperature, °F	Fluid temperature, °F
WEST VIRGINIA--Continued																
Boone:																
Alma	240	8.5	3.2	36.4	21.8	34.8	1.0	0.09	1.9	0.7	0.2	0.8	2.3	2,050	2,160	2,420
Campbell Creek	241	11.6	.6	52.4	27.7	11.8	1.7	.10	.9	1.1	.2	2.6	.9	2,620	2,730	2,870
Do	242	5.2	1.6	43.1	27.8	21.5	1.7	.84	1.9	.7	.5	1.5	2.2	2,000	2,350	2,600
Cedar Grove	243	3.3	.8	45.1	35.8	7.7	1.3	.07	1.9	.8	1.6	2.3	2.6	2,780	2,910	2,910+
Do	244	8.6	.9	49.0	33.0	7.4	1.7	.16	1.8	.9	.6	3.0	1.5	2,780	2,880	2,910+
Do	245	6.3	1.3	48.2	29.2	14.0	1.7	.11	1.9	1.1	.4	1.8	1.7	2,750	2,790	2,860
Coalburg	246	14.3	.9	54.0	34.5	5.2	1.5	.51	1.9	1.0	.3	3.1	.6	2,910+	-	-
Hernshaw	247	4.5	.7	62.8	26.4	4.3	1.6	.05	2.2	.3	.7	.7	1.2	2,910+	-	-
Lower Kittanning	248	27.9	.4	63.6	28.8	2.4	1.4	.06	1.8	1.0	.3	3.1	.3	2,910+	-	-
Stockton-Lewiston	249	11.0	.9	56.3	33.6	5.1	2.0	.06	2.0	.4	.3	1.6	.6	2,910+	-	-
Winifrede	250	13.0	.8	58.1	31.8	3.8	1.7	.05	.9	.9	.2	3.2	.7	2,910+	-	-
Do	251	8.2	.7	58.4	32.5	3.5	1.9	.08	2.0	.8	.3	2.1	1.1	2,910+	-	-
Do	252	8.5	.5	61.5	22.3	3.7	1.4	.08	4.2	1.0	.3	.9	6.6	2,470	2,680	2,780
Do	253	14.7	.9	56.4	31.8	5.9	1.1	.25	1.8	.7	.3	3.5	.6	2,910+	-	-
Braxton:																
Pittsburgh	254	5.9	1.1	38.1	25.7	19.7	.9	.19	8.7	1.8	.3	1.6	3.3	2,310	2,360	2,480
Upper Kittanning	255	4.8	.8	54.1	31.0	5.0	1.6	.10	2.3	1.0	.6	2.1	2.6	2,910+	-	-
Clay: Lower Kittanning	256	7.1	.7	52.3	32.6	5.7	3.3	.06	1.8	.9	.2	1.9	1.3	2,910+	-	-
Fayette:																
Campbell Creek	257	6.3	.8	48.5	30.1	13.6	1.1	.07	1.8	.8	.7	2.6	1.3	2,780	2,840	2,910
Lower Eagle	258	6.0	.9	53.1	31.3	9.9	1.1	.11	1.8	.8	1.3	2.2	.8	2,830	2,890	2,910+
Lower Kittanning	259	5.9	.7	52.9	31.2	9.1	2.0	.23	1.7	.5	.3	.9	1.3	2,910+	-	-
Gilmer: Pittsburgh	260	7.7	2.0	35.6	22.8	26.5	1.2	.27	9.5	.8	.4	1.4	3.4	2,130	2,190	2,270
Greenbrier: Sewell	261	4.6	1.0	47.1	28.2	15.8	1.1	.20	1.9	.9	1.2	3.2	1.5	2,180	2,330	2,580
Harrison:																
Pittsburgh	262	9.9	4.7	26.5	22.0	47.8	.8	.23	1.7	.4	.5	.8	2.8	1,940	2,140	2,440
Do	263	9.2	4.3	25.8	18.3	38.4	.8	.42	9.2	1.5	1.0	.9	5.1	1,910	2,100	2,310
Do	264	8.0	3.4	29.9	19.8	29.9	.8	.72	10.9	1.4	.9	.9	5.2	2,100	2,260	2,480
Do	265	8.2	3.6	29.6	16.0	39.4	.7	.59	8.7	.9	.7	.9	3.2	2,020	2,080	2,190
Do	266	10.2	6.0	22.0	14.1	56.3	.6	.97	2.4	.6	.6	.9	2.5	2,020	2,110	2,360
Do	267	13.1	5.6	30.9	18.2	44.6	.9	.14	2.0	.4	.5	.7	1.5	2,020	2,100	2,430
Do	268	7.8	4.2	30.4	19.5	41.8	1.0	.06	2.4	1.0	.6	1.1	3.2	2,150	2,280	2,440
Redstone	269	7.8	3.8	23.8	17.9	39.1	.6	.38	12.7	.6	.3	.9	6.0	2,040	2,090	2,280
Do	270	7.4	2.0	42.9	26.6	16.1	1.2	1.3	5.6	.6	.3	1.6	5.2	2,280	2,360	2,620
Do	271	8.0	3.3	37.9	20.6	26.6	.9	.20	6.7	1.0	.2	1.6	3.8	2,080	2,160	2,400
Do	272	5.9	2.5	27.6	22.5	34.7	1.0	.34	6.8	1.2	.2	1.6	6.7	2,230	2,400	2,570
Kanawha:																
Campbell Creek	273	4.5	.8	39.7	25.8	10.9	1.2	3.0	8.5	1.8	.9	2.0	5.9	2,310	2,380	2,470
Do	274	7.2	1.8	53.0	29.2	15.1	1.5	.10	1.9	.2	.4	1.0	1.1	2,550	2,620	2,730
Do	275	4.5	1.0	41.3	32.8	16.7	1.3	.05	1.9	.8	.7	1.5	2.7	2,620	2,680	2,850
Do	276	3.2	1.1	38.2	31.9	19.1	1.0	.07	2.6	.8	1.1	1.9	3.8	2,310	2,370	2,660
Do	277	9.4	1.7	51.6	30.0	12.6	1.9	.05	1.6	1.0	.4	2.0	.7	2,730	2,780	2,850
Do	278	6.4	.5	48.9	29.8	16.0	1.7	.14	1.8	.3	.6	1.8	.6	2,780	2,910+	-
Cedar Grove	279	5.3	.9	50.2	33.0	9.1	1.4	.13	1.8	.7	.8	1.7	1.9	2,800	2,890	2,910+
Do	280	4.8	1.3	38.2	31.4	20.2	.8	.10	1.8	1.0	.4	3.1	2.9	2,250	2,300	2,360
Do	281	6.5	1.7	37.9	23.8	31.4	1.4	.05	2.0	.5	.5	.5	2.9	1,990	2,150	2,530
Coalburg	282	12.2	.8	57.9	34.0	3.1	2.1	.09	1.8	.7	.4	2.1	.3	2,910+	-	-
Do	283	11.9	.7	60.2	34.6	2.2	1.9	.04	2.2	.4	.3	1.5	.5	2,910+	-	-
Eagle	284	4.9	.8	54.4	31.8	7.7	2.3	.14	2.4	.5	.6	1.8	1.1	2,910+	-	-
Eagle A	285	3.8	.6	55.0	31.7	9.1	1.9	.06	2.2	.3	.4	1.1	1.2	2,910+	-	-
Lower Kittanning	286	4.1	.7	51.2	37.9	5.7	2.0	.17	2.0	.5	.2	1.1	1.1	2,910+	-	-
Do	287	6.7	.8	46.8	35.2	8.8	1.6	.05	2.1	1.2	.4	3.0	1.7	2,910+	-	-
Do	288	12.0	.6	58.8	32.8	3.7	2.3	.11	1.8	.6	.1	2.2	.6	2,910+	-	-
Do	289	14.3	.7	57.9	31.8	3.9	1.9	.05	1.9	.8	.2	2.7	.4	2,910+	-	-
Do	290	6.1	1.0	52.2	36.0	9.0	1.4	.04	1.9	.3	.2	.2	1.2	2,570	2,660	2,740
Do	291	13.9	2.4	47.9	28.6	19.8	1.7	.08	1.8	.3	.1	1.0	.7	2,590	2,640	2,700
Do	292	15.7	2.2	50.1	28.6	15.9	2.2	.09	1.7	.2	.1	1.0	.8	2,780	2,840	2,890
Pittsburgh	293	7.0	2.1	41.1	23.1	28.8	1.2	.23	1.5	.7	.2	1.2	1.4	2,050	2,160	2,320
Do	294	6.4	2.0	41.3	25.3	29.5	1.0	.14	1.8	.5	.2	1.1	1.5	2,210	2,300	2,490
Powellton	295	10.9	.9	52.4	32.0	7.2	1.6	.04	.4	1.5	.4	4.2	.7	2,850	2,910	2,910+
Stockton-Lewiston	296	7.1	.7	47.8	36.0	5.2	1.8	1.8	2.0	.6	.4	1.4	1.1	2,910+	-	-
Do	297	6.1	.8	56.4	33.7	3.5	1.9	.30	1.4	.6	.5	1.4	.7	2,910+	-	-
Do	298	8.	.9	58.7	31.7	4.8	1.6	.18	1.8	.4	.3	.6	.4	2,910+	-	-
Upper Kittanning	299	10.0	1.2	52.2	29.5	10.3	1.2	.09	1.8	.7	.3	2.2	1.5	2,800	2,900	2,910+
Winifrede	300	3.6	.7	49.3	36.4	5.9	.8	.06	1.9	.9	.3	.8	3.3	2,910+	-	-
Do	301	10.2	.7	60.5	26.5	4.2	1.5	.04	4.7	1.3	.4	1.9	1.7	2,520	2,630	2,730
Lewis:																
Pittsburgh	302	9.4	3.8	35.0	18.9	35.9	1.0	.29	2.0	1.3	.6	2.0	2.4	2,060	2,220	2,410
Do	303	9.2	2.6	36.7	25.7	27.7	.8	.55	3.3	.8	.4	1.4	3.2	2,100	2,140	2,580
Redstone	304	8.6	3.6	30.5	19.4	39.2	.6	.13	5.0	.6	.2	1.7	2.9	2,080	2,130	2,320
Logan:																
Campbell Creek	305	7.9	.6	58.2	30.0	3.8	1.7	.06	1.7	.4	.2	.7	1.5	2,750	2,690	2,910+
Cedar Grove	306	8.6	2.4	45.5	26.7	22.6	1.0	.11	2.2	.4	.3	1.7	1.7	2,120	2,210	2,430
Chilton	307	13.9	.6	57.1	38.2	3.1	1.5	.08	2.0	.4	.1	.5	.8	2,910+	-	-
Do	308	2.9	.7	46.2	33.6	9.4	1.4	.08	2.0	.9	1.7	1.4	2.2	2,700	2,800	2,890
Lower Kittanning	309	9.5	.7	64.5	29.0	2.1	1.2	.05	1.7	.2	.2	.6	.6	2,910+	-	-

APPENDIX II (Concluded)

County and bed	Sample No.	Percent of moisture-free coal		Analysis of ash, percent									Fusibility of ash		
		Ash	Sulfur	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	Na_2O	K_2O	SO_3	Initial deformation temperature, °F	Softening temperature, °F	Fluid temperature, °F
WEST VIRGINIA--Continued																
Marion:																
Pittsburgh	310	7.5	2.7	39.6	21.8	23.9	1.0	0.12	9.2	1.7	0.6	1.0	4.5	2,190	2,250	2,310
Sewickley	311	11.7	4.0	41.7	23.6	19.7	1.1	.02	5.4	1.6	.7	2.4	3.7	2,140	2,190	2,430
Mason: Pittsburgh	312	14.9	3.1	43.9	27.3	18.4	1.0	.38	3.7	1.0	.2	1.5	2.7	2,240	2,360	2,520
McDowell: Pocahontas No. 3	313	6.7	.7	48.5	29.1	10.4	1.1	.07	4.4	1.4	.8	1.6	1.6	2,520	2,570	2,620
Mingo:																
Alma	314	3.9	.7	46.0	36.8	7.3	1.7	.06	1.9	3.8	.5	1.2	2.9	2,910+	-	-
Campbell Creek	315	5.7	.9	48.2	32.9	10.8	1.7	.44	1.9	1.2	.8	2.6	1.3	2,770	2,910	2,910+
Cedar Grove	316	3.4	.6	49.2	30.8	8.9	1.1	.07	1.9	1.2	2.1	.4	3.0	2,700	2,760	2,850
Eagle	317	4.3	1.2	45.1	26.2	18.0	1.1	.11	2.0	1.2	1.2	2.0	3.1	2,120	2,260	2,340
Monongalia:																
Pittsburgh	318	9.0	3.7	36.1	24.4	26.0	.7	.23	4.5	2.0	1.5	1.2	5.6	2,090	2,260	2,420
Do	319	9.0	2.9	41.1	25.0	27.5	1.1	.18	1.7	.8	.8	1.6	1.6	2,000	2,120	2,400
Do	320	9.2	3.1	39.8	22.3	28.7	.9	.07	1.8	.7	.8	1.4	1.3	2,010	2,070	2,380
Do	321	7.7	3.3	41.7	23.5	22.6	1.1	.18	3.6	.8	.4	1.5	3.5	1,930	2,130	2,430
Redstone	322	11.0	1.3	56.5	26.2	7.6	1.3	.81	2.0	.9	.2	2.2	1.8	2,600	2,700	2,790
Do	323	11.9	3.3	47.0	24.4	23.3	1.2	.04	1.8	.5	.2	2.2	1.3	2,140	2,240	2,590
Sewickley	324	11.5	3.5	41.8	23.9	28.7	1.1	.08	1.7	.8	.4	2.0	1.6	2,150	2,230	2,340
Upper Freeport	325	14.3	1.0	55.5	32.5	6.1	1.3	.30	1.8	.9	.2	2.5	.7	2,780	2,910	2,910+
Do	326	14.3	2.1	49.9	27.7	16.1	1.5	.11	.9	.8	.2	2.4	1.0	2,360	2,540	2,660
Upper Kittanning	327	9.8	2.2	41.9	29.7	22.7	1.2	.07	1.9	.6	.2	1.7	1.0	2,470	2,580	2,700
Waynesburg	328	14.5	2.4	51.0	27.5	16.2	1.0	.13	1.7	.6	.3	2.7	.3	2,590	2,680	2,830
Do	329	17.6	2.7	50.6	29.0	14.4	1.3	.16	1.8	.9	.3	2.5	.6	2,600	2,730	2,780
Do	330	17.4	.9	57.8	30.6	5.2	1.7	.30	1.8	.8	.3	3.1	.4	2,870	2,910+	-
Nicholas:																
Campbell Creek	331	4.9	1.1	40.8	29.7	16.1	1.0	1.6	2.8	1.3	.9	2.2	3.1	2,210	2,310	2,620
Do	332	7.0	.8	50.9	30.0	6.9	1.5	1.4	1.7	1.0	.5	2.5	2.2	2,750	2,840	2,910+
Do	333	3.3	1.1	33.4	31.3	23.3	1.0	1.1	3.2	1.1	.9	1.1	4.8	2,130	2,230	2,420
Coalburg	334	6.8	.8	50.3	35.4	5.6	1.7	1.2	1.7	.6	.4	1.4	1.2	2,910+	-	-
Eagle	335	7.8	.9	51.3	31.9	8.6	1.7	.21	1.9	.9	.3	2.3	1.2	2,830	2,900	2,910+
Do	336	5.2	.7	48.8	33.1	8.3	1.5	.13	1.8	1.3	1.2	2.2	1.9	2,810	2,860	2,890+
Lower Kittanning	337	4.8	.9	46.3	32.1	12.2	1.7	.05	1.9	1.1	.5	1.3	3.6	2,680	2,780	2,860
Sewell	338	3.7	.6	52.5	31.4	6.5	1.5	.25	2.1	1.0	1.3	2.1	1.9	2,910+	-	-
Upper Kittanning	339	9.5	.7	59.4	26.7	2.6	1.6	.10	1.8	1.0	.6	1.4	3.5	2,890	2,910+	-
Winifrede	340	8.4	.8	59.3	33.0	3.0	1.8	.08	1.7	.3	.3	1.0	1.0	2,910+	-	-
Pocahontas: Sewell	341	4.9	.5	42.0	37.2	10.6	1.3	1.1	1.9	.8	1.5	1.3	2.4	2,680	2,890	2,910+
Preston:																
Bakerstown	342	10.6	4.4	34.4	19.7	42.0	.9	.06	1.8	.3	.2	.7	1.9	1,900	2,010	2,430
Do	343	17.3	3.2	48.0	24.6	21.7	1.3	.46	1.7	1.1	.2	2.0	.9	2,020	2,210	2,480
Do	344	8.0	3.9	26.5	19.6	49.7	.9	.11	2.9	.9	.2	1.0	2.7	2,020	2,440	2,580
Do	345	10.6	3.4	41.7	20.5	31.5	.8	.24	1.8	.7	.2	1.1	1.8	1,950	2,110	2,380
Lower Freeport	346	15.7	4.4	37.8	24.7	33.8	.8	.42	1.7	.3	.1	1.5	.8	2,110	2,190	2,360
Lower Kittanning	347	9.5	.8	46.9	40.3	3.4	1.8	.82	1.8	.7	.2	2.1	1.4	2,910+	-	-
Do	348	11.1	1.9	44.3	29.8	16.3	1.4	.50	1.9	.5	.2	1.2	1.7	2,600	2,680	2,740
Mahoning	349	17.4	1.5	52.4	29.8	10.5	1.4	.11	1.8	.9	.3	2.9	.9	2,670	2,760	2,850
Upper Freeport	350	13.8	1.0	53.9	29.8	8.1	1.6	.25	1.8	.8	.2	2.3	.8	2,780	2,860	2,910+
Do	351	16.2	2.5	49.8	23.1	20.6	1.1	.11	1.9	.7	.1	1.9	.9	2,440	2,510	2,650
Do	352	6.6	1.0	46.5	30.7	10.9	1.3	.42	1.7	1.0	.3	2.2	2.2	2,620	2,730	2,860
Do	353	82.6	.7	56.7	37.8	2.8	1.7	.42	1.8	.9	.2	3.0	.3	2,910+	-	-
Do	354	7.8	.9	49.4	34.9	4.6	1.5	.68	2.1	.8	.3	2.4	1.7	2,910	2,910+	-
Upper Kittanning	355	9.3	2.6	40.3	26.0	27.9	1.2	.39	1.8	.8	.2	1.8	1.6	2,180	2,360	2,600
Putnam: Pittsburgh	356	7.7	1.9	46.6	26.7	21.2	1.3	.62	1.7	.6	.3	1.4	2.6	2,130	2,240	2,440
Raleigh:																
Eagle	357	7.6	1.5	51.6	27.1	13.6	1.7	.37	1.8	.6	.6	1.7	1.4	2,330	2,620	2,690
Do	358	8.1	1.5	50.6	30.5	13.7	1.9	.17	2.0	.4	.4	1.2	.9	2,700	2,780	2,840
Randolph:																
Campbell Creek	359	2.1	.9	23.6	27.1	26.9	1.1	.44	7.2	1.8	1.1	1.0	9.6	2,310	2,360	2,550
Lower Kittanning	360	9.9	.8	47.0	41.6	2.6	1.6	.83	1.8	1.0	.3	1.7	1.1	2,910+	-	-
Sewell	361	3.9	.7	44.7	36.2	7.6	1.5	.12	1.9	.9	1.0	1.9	3.5	2,850	2,910+	-
Tucker: Upper Freeport	362	10.6	2.8	39.2	26.3	31.1	1.1	.24	1.7	.4	.2	1.4	1.1	2,140	2,260	2,530
Upshur:										-						
Pittsburgh	363	10.2	4.8	28.1	19.0	48.1	.5	.34	3.1	.4	.2	1.4	2.0	2,050	2,130	2,260
Redstone	364	6.2	1.5	36.5	25.2	20.9	.9	1.1	7.9	1.2	.3	1.8	5.6	2,210	2,260	2,360
Do	365	8.7	3.0	34.2	22.5	32.6	.8	.42	4.8	.8	.6	1.7	2.9	2,020	2,160	2,400
Upper Freeport	366	12.2	1.2	48.2	30.3	11.2	1.3	1.7	1.8	.6	.2	2.3	1.9	2,570	2,680	2,890
Upper Kittanning	367	15.0	1.2	48.6	34.5	10.6	1.5	.76	1.8	.6	.1	1.7	.4	2,800	2,890	2,910+
Webster: Fire Creek	368	8.0	.5	54.9	36.9	3.8	1.7	.14	1.8	.2	.1	.2	.7	2,910+	-	-
Wyoming:																
Beckley	369	7.5	.8	51.3	33.0	6.1	2.0	1.5	1.9	.4	1.3	1.3	.6	2,910+	-	-
Pocahontas No. 4	370	6.3	.8	51.3	35.5	8.1	1.4	.11	2.0	.4	1.0	.5	.8	2,910+	-	-
Powellton	371	6.5	.7	52.7	32.3	6.7	.9	.07	1.7	1.6	1.0	1.0	1.2	2,640	2,780	2,910+
WYOMING																
Carbon:																
Unknown	372	6.4	0.6	24.5	14.2	9.0	0.9	0.21	10.8	4.7	0.1	0.5	16.4	2,450	2,510	2,630
Do	373	14.4	1.8	38.6	19.6	10.5	1.8	.51	9.4	4.4	.2	.6	16.1	-	-	-

APPENDIX III

ASH UTILIZATION (TONS) 1969-1971 (11)

Applications	1969			1970			1971		
	fly ash	bottom ash	boiler slag	fly ash	bottom ash	boiler	fly ash	bottom ash	boiler slag
I. Cement									
A. In type 1-P cement (ASTM595-71) As a pozzolan (mixed with cement)	32,759	-----	-----	12,293	-----	-----	16,536	-----	-----
B. As a raw material for cement clinker	132,226	5,000	-----	146,191	5,850	-----	104,222	-----	91,975
C. Partial replacement of cement									
1. concrete products (block, etc.)	175,086	5,686	-----	168,129	1,900	3,368	177,166	35,377	76,563
2. structural concrete	194,322	-----	-----	238,766	-----	-----	185,467	-----	-----
3. mass concrete-dams	163,809	-----	-----	129,415	-----	-----	71,411	-----	-----
II. Road base stabilization	264,224	20,619	73,240	111,019	18,125	70,309	36,939	7,880	49,564
III. Lightweight aggregate	250,251	19,388	-----	207,091	50,522	-----	178,895	13,942	-----
IV. Fill material for roads, construction, etc.	73,440	1,102,240	548,606	320,304	774,828	497,876	363,385	533,682	2,628,885
V. Filler in asphalt mix	114,967	10,084	89,970	131,270	-----	27,077	147,655	2,833	81,700
VI. No cost removal from utility	452,522	381,076	48,387	526,347	377,898	16,156	1,872,728	542,895	381,775
VII. Miscellaneous	244,508	648,052	257,204	167,302	613,829	479,576	98,802	475,417	428,026
Oil well cementing	81,427	-----	-----	-----	-----	-----	70,115	-----	-----
Mine fire control	60,772	-----	-----	-----	-----	-----	------	-----	-----
Mine subsidence control	31,750	-----	-----	-----	-----	-----	------	-----	-----
Unclassified	5,983	1,620	26,266	-----	-----	-----	20,314	39,491	65,003

APPENDIX III (continued)

ASH UTILIZATIONS (TONS) 1969-1971

Applications	1969			1970			1971		
	Fly ash	bottom ash	boiler slag	fly ash	bottom ash	boiler slag	fly ash	bottom ash	boiler slag
VII. Miscellaneous (cont.)									
An abrasive for cleaning	34	-----	19,344	-----	-----	-----	-----	-----	-----
Spontaneous combustion control	32,000	32,000	-----	-----	-----	-----	-----	-----	-----
Highway bridges	11,361	-----	-----	-----	-----	-----	-----	-----	-----
Test caps	3	-----	-----	-----	-----	-----	-----	-----	-----
Refractory add mix	80	-----	-----	-----	-----	-----	-----	-----	-----
Insulating cement	702	-----	-----	-----	-----	-----	-----	-----	-----
Grouting	3,832	-----	-----	-----	-----	-----	-----	-----	-----
Snow sanding	800	-----	-----	-----	-----	-----	1,795	-----	-----
Pipe coating	1,445	-----	-----	-----	-----	-----	5,500	-----	-----
Foundaries sand	1,550	-----	-----	-----	-----	-----	-----	-----	-----
manufacturer products	2,300	-----	-----	-----	-----	-----	-----	-----	-----
Chemical products	250	-----	-----	-----	-----	-----	230	-----	-----
Poz-o-pac	475	-----	-----	-----	-----	-----	-----	-----	-----
Sewage treatment plants (filtration)	3,000	-----	-----	-----	-----	-----	-----	-----	-----
Subsurface courses (heavy construction)	2,819	-----	-----	-----	-----	-----	-----	-----	-----
Ready mix	2,205	-----	-----	-----	-----	-----	-----	-----	-----
Oil well drilling	1,570	-----	-----	-----	-----	-----	-----	-----	-----
Industrial testing	150	-----	-----	-----	-----	-----	468	-----	2,000
Vanodium recovery	-----	15	273	-----	-----	-----	241	2,180	2,327
Ice control	-----	441,039	34,567	-----	-----	-----	139	271,635	131,098

APPENDIX III (concluded)

ASH UTILIZATION (TONS) 1969-1971

Applications	1969			1970			1971		
	Fly ash	bottom ash	boiler slag	fly ash	bottom ash	boiler slag	fly ash	bottom ash	boiler slag
VII. Miscellaneous (cont.)									
Outdoor school tracks	------	1,000	-----	-----	-----	-----	-----	-----	-----
Asphalt shingles	-----	108,877	5,033	-----	-----	-----	-----	67,831	-----
Sandblasting grit	-----	38,902	128,843	-----	-----	-----	-----	25,577	122,072
Dike repair and buildings	-----	21,813	-----	-----	-----	-----	-----	-----	-----
Drainage filter	-----	2,786	200	-----	-----	-----	-----	-----	-----
Aggregate	-----	-----	42,678	-----	-----	-----	-----	-----	63,246
Landfill	-----	-----	-----	-----	-----	-----	-----	68,703	5,574
Agriculture	-----	-----	-----	-----	-----	-----	-----	-----	23,727
Dust control	-----	-----	-----	-----	-----	-----	-----	-----	600
Seal coating	-----	-----	-----	-----	-----	-----	-----	-----	12,929